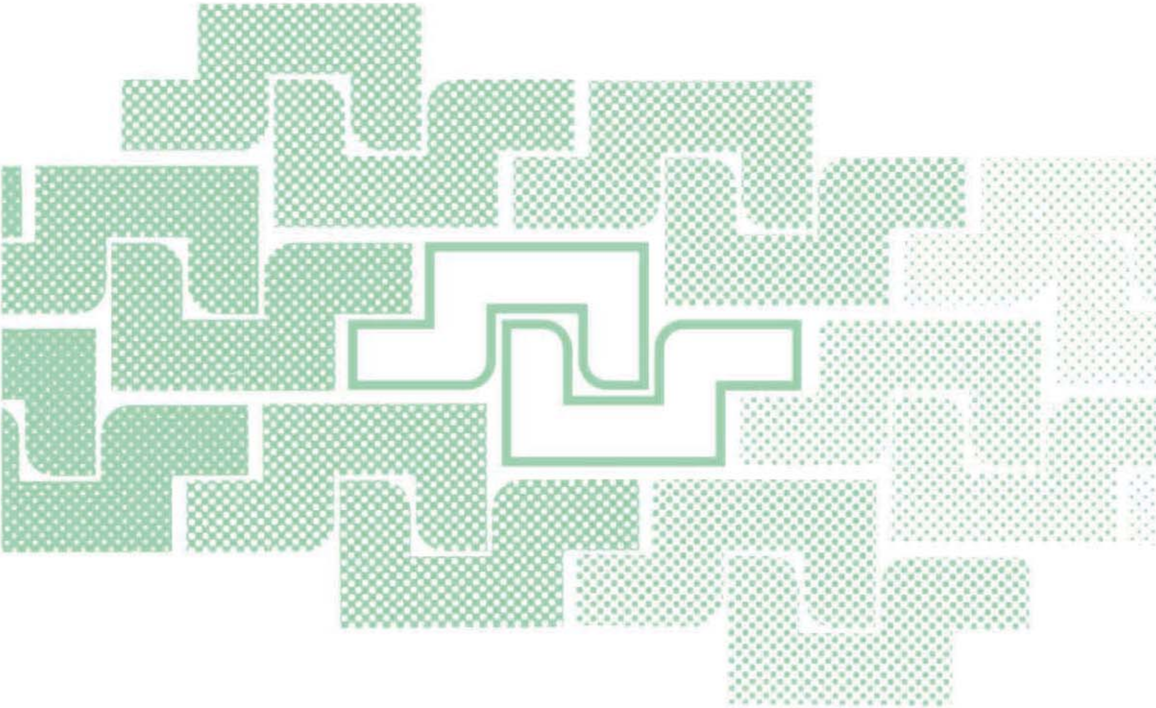

Environmental Role of Wetlands in Headwaters

Edited by

Josef Krecek and Martin Haigh

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IV. Earth and Environmental Sciences – Vol. 63

Environmental Role of Wetlands in Headwaters

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PREFACE

The NATO Advanced Research Workshop (ARW) on the *"Environmental Role of Wetlands",* the second NATO –ARW organised under the umbrella of the International Association for Headwater Control (IAHC), arose from the *"Nairobi Declaration for the International year of Freshwaters"*. This was an outcome from the *Fifth International Conference on Headwater Control*, which was promoted by the United Nations University with five other UN Agencies and a cluster of NGOs including the IAHC and World Association for Soil and Water Conservation. Sincere thanks go to all involved.

The Declaration responded to concerns about water supply and declining river flow in Africa and to wider concerns that the role of wetland areas, especially those in upstream areas, had been neither fully explored nor appreciated. It argued that the significance of these headwater wetlands needed more systematic examination and advocated a special workshop to focus on the role of headwater wetlands in their contexts, both biophysical and socio-economic. In fulfilment of this direction, this publication offers a multi-disciplinary, multi-functional overview of the role played by, and management problems associated with, wetlands in headwater areas. It also examines their place in future strategies of integrated watershed management.

The organisers and participants of this workshop send their deep thanks and appreciation to the NATO Science Division for helping the headwater control movement achieve this goal. Thanks go also for their patient facilitation of this exploration of wetlands in context, especially their helpful support during the development, financing and delivery of this event. Sincere thanks are also due to the IAHC for their tireless engagement with the logistics of fielding the workshop and enabling participant travel and liaison with our kind hosts in the City of Marienbad and its excellent Park Hotel Golf. The IAHC support of the preparation of these proceedings is also warmly acknowledged, especially the editorial contributions of David Hardekopf. We hope that this book, the outcome of this work, the first that strives to understand wetlands in their headwater contexts, will support the sustainable management and development of watersheds around the world.

Martin Haigh and Josef Krecek
Teplice, April 2005.

HEADWATER WETLANDS

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KEYWORDS / ABSTRACT: Headwaters / wetlands / conservation / environmentally sound management / Ramsar convention / downstream impacts / surface water chemistry / global climate change /

A gulf remains between the practical concerns of environmental managers and the research interests of most academic environmental scientists. There is a scarcity of published work that integrates the wider concerns of environmental managers with academic research into the hydrological and hydro-chemical functioning of catchments at different scales. This volume is devoted to attempts by those, mainly concerned with environmental management in practice at the local and regional scale, to see the headwater wetlands in their context. The main issue addressed is- if a headwater regions contains wetland, what are the implications of this fact for environmental management and how does the wetland affect the management of the basin as a whole.

1. Introduction

Generally, wetlands are considered as lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface [1]. Often, their hydrological attributes have commanded pride of place in lists of functions and values [5].

Wetlands include swamps, marshes, bogs and similar areas, varying widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation, and other factors, including human disturbance [8].

Nowadays, one of the main priorities of several national water programmes is restoring and protecting wetlands recognized as important water sources [11]. In the case of the drinking water programme, the

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treatment possibilities are limited; the effort to protect quality of headwaters (sources of the water) is increasing. Therefore, ensuring not net loss of headwater wetlands will remain a basic priority, not only to meet Clean Water Act goals and requirements, but also to advance source water protection.

Currently, the minimum global estimate of wetlands is considered to be 7.8 million sq. km (Conference on Parties to the Convention on Wetlands, 1999, [11]) but the number will be still increasing.

2. Ramsar Convention

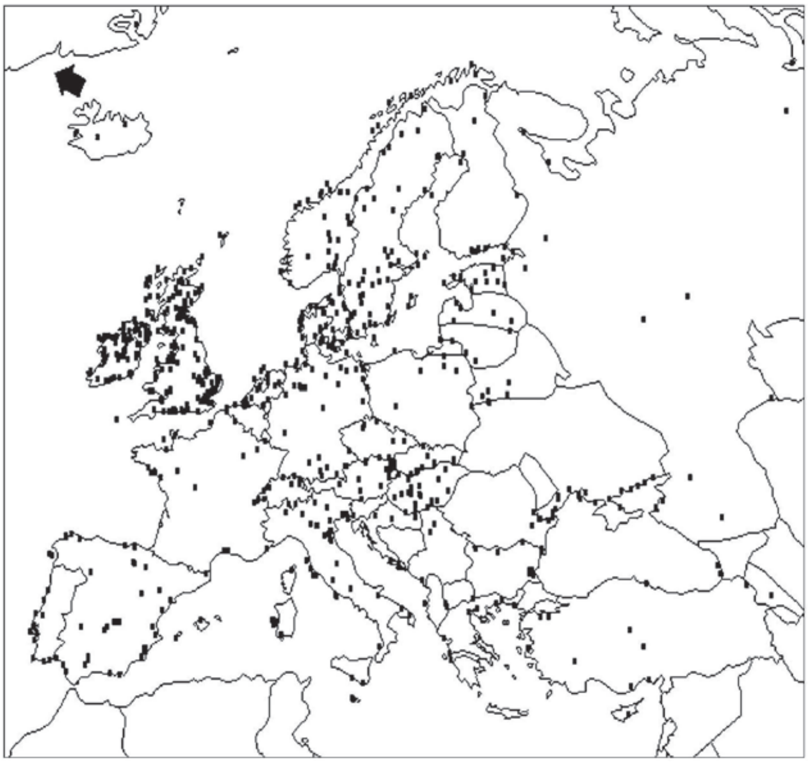

Figure 1. Wetlands of International Importance in Europe: 736 Ramsar Sites.

The Convention on Wetlands, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. There are presently 144 Contracting Parties to the Convention; 1421 w etland sites, covering 123.9 million hectares, are designated in the Ramsar List of Wetlands of International Importance.

Most of the Ramsar sites are lowland wetlands (floodplains). However, from the total area of wetlands (5.7 million sq. km: 6% of the Earth's land surface) registered by the World Conservation Monitoring Centre [8], 30% are headwater peat bogs while 15% of wetlands are found on floodplains.

In Europe, 736 Ramsar sites (Figure 1) were established to conserve unique example of natural or near-natural wetlands supporting extraordinary biodiversity (ecological communities and species, especially water birds or fish). Unfortunately, the biocentric approach of Ramsar conservation (even when supported by national governments) does not reflect the global problems and environmental threats (global climate change, acid atmospheric deposition etc) that headwater wetlands are facing now.

3. Headwater control

Headwater control is an integrating approach. It seeks to combine the perspectives, resolve the conflicts and satisfy the needs of all stakeholders. This book seeks to examine the special role played by headwater wetlands within the wider contexts of environmental management. These can be very significant, even when the actual area of such wetland is small, which is often the case in lower latitudes.

The value of the service provided by headwater wetlands value is estimated as an economic benefit of 2.8 trillion USD/year [11]. These wetlands providing benefits in the fields of:

- water supply, retention and flood mitigation
- control of water quality
- timber production
- wildlife and biodiversity conservation
- tourism
- cultural heritage
- source of aesthetic inspiration, local tradition and religion

Headwater wetlands (peat-bogs and fens) rank among the world's ecosystems most threatened by human actions. They face the local impacts of development and land use conversion (especially drainage, forestation, over-exploitation (e.g. mining), point or non/point pollution) and also the larger scale effects of global climatic change, air pollution, acid atmospheric deposition and so forth.

Headwater peat-bogs are unique ecological communities that can be destroyed in a matter of days, but require hundreds of years to form naturally. Generally, bogs are associated with low temperatures and short growing seasons where ample precipitation and high humidity cause excessive moisture to accumulate. Therefore, most bogs are found in the northern states where they often form in old glacial lakes. They may have either considerable amounts of open water surrounded by floating vegetation or vegetation may have completely filled the lake (terrestrialisation). The sphagnum peats of northern bogs cause especially acidic waters. The result is a wetland ecosystem with a very specialized acidophile flora and fauna. These lands support many species of plants in addition to the characteristic sphagnum moss, including cotton grass, cranberry, blueberry, pine, Labrador tea, and tamarack. Moose, deer, and lynx are a few of the animals that can be found in northern bogs.

Headwater fens are peat-forming wetlands that receive nutrients from sources other than precipitation: usually from upslope sources through drainage from surrounding mineral soils and from groundwater movement. Fens differ from bogs because they are less acidic and have higher nutrient levels. Fens may be dominated by woody or herbaceous vegetation.

4. Management

Although special policies may be required for the effective management of headwater wetlands, *a priori*, it seems likely that these strategies should be guided by the wider frameworks of headwater control. The factors that affect this book’s concern to examine wetlands in a headwater context include:

- trying to achieve the sustainable use of wetlands by addressing development issues whilst minimizing environmental impacts through the:
    - involvement of local communities,
    - limitation of forest and agriculture practices,
    - rehabilitation of degraded wetlands;
- including headwater wetlands within integrated watershed management programmes in order to:

- consider their down-stream benefits and impacts, as well as their local effects in a headwater context,
- secure ethical management by building respect for local stakeholder needs and rights,
- foster a concern for sustainable environmental stewardship amongst local communities and among all environmental managers,
- build a function partnership between stakeholders (land users, landowners, enterprises, local through national legislatures, communities and NGOs, perhaps through the creation of watershed councils

5. Policy

Frequently, headwater wetlands are controlled by a fragmented system of legislature in the frame of many disparate aspects of national policy. Typically, this administrative framework is more oriented to regulating the services provided by headwater wetlands than to the well being of the headwater environments themselves. Commonly, this framework includes:

- Forest Acts (protective forest stands, commercial forest production),
- Water Acts (protected headwater regions, streams and reservoirs of drinking water supply),
- Public Health Acts (hygienic buffer zones in drinking water catchments),
- Nature Conservation Acts (national parks, protected landscapes, nature reserves or monuments),
- Acts on the Environment (EIA and SEA procedures, managing spots of ecological stability)

The fact that current legislation is still based on the concept of a ministerial approach, which is not well suited to ensuring sustainable development, is a serious problem. Generally, the existing legislative is effective in the conservation of limited spots. Unfortunately, the integrating approach reflecting global aspects of environmental problems is still missing. This book is devoted to the examination of headwater wetland sin their wider context.

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MAPPING WETLANDS IN EUROPEAN HEADWATER AREAS

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KEYWORDS / ABSTRACT: Europe / wetlands / headwaters / mapping

The paper describes the first approach to wetlands mapping in headwater areas at the continental scale. Given the size of the minimum mapping unit it is evident that a class like wetlands is underestimated in the final assessment, as it is often characterized by objects smaller than 25 ha. It is known that this is a drawback affecting in particular the "water" classes of the CORINE classification. The following assessment has been carried out on the area covered by CORINE data, covering the EU15 Countries (excluding Sweden) plus Poland, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, Bosnia and Herzegovina, Albania, Macedonia, for a total of 4,650,000 ha. Using a 250-meter resolution DEM, only headwater areas larger than 1 km^2 are reported in the presented map of headwaters in south-western Europe. The process of mapping can be further developed by deeper characterising the identified areas, for example by assigning them to corresponding drainage basins, altitudinal areas, landscape or administrative units. The results are based on the data available. Updating and improvement will be possible in the short term with the delivery of the new CORINE 2000 system (based on satellite images acquired between 1999 and 2001) and using more detailed Digital Elevation Models (e.g. Shuttle Radar Topography Mission).

1. Introduction

Over the last century or so, wetlands in Europe have undergone thorough changes. Many of them have been drained, exploited and/or converted to arable land or settlements. Only during the last decades of the 20th century has the importance of wetlands been highlighted by the scientific community and recognised by the general public. An important role in this process was played by NGOs active in the field of environmental protection. The value of wetlands as habitat for many endangered species

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or as rest sites for migrating birds, for example, is highlighted in an extended body of literature.

At the same time, it has been recognised that wetlands are particularly sensitive areas and that European and national policies, especially in the agricultural sector, are likely to result in continued pressure on these precious resources. If the protection of wetlands in Europe is to be efficient, a first step should be an exhaustive survey of their distribution and characteristics across Europe. This is a non-trivial task, since relevant information is not always easily accessible and needs to be updated on a regular basis.

This paper describes a first attempt to map wetlands in headwater areas across Europe. It is based on the analysis of CORINE land cover data in combination with data on European rivers and catchments elaborated in the framework of the CCM Activity of the Institute for Environment and Sustainability at the European Commission's Joint Research Centre.

2. Developing a GIS for European environmental data

European-wide spatial datasets with relevant information for assessing the state of the environment have been collected by Eurostat since 1992. Eurostat, for example, elaborated geographical layers and statistical information on land use, soils, hydrography, natural resources and transportation networks through its GISCO (Geographic Information System for the European Community) project. These layers correspond to mapping scales between 1:500,000 and 1:3,000,000 and are useful for a general overview and for overall assessments. More detailed data exist at national, regional and local levels and efforts for harmonization, integration and management of these data through a modern spatial data infrastructure are bundled under the so-called INSPIRE (Infrastructure for Spatial Information in Europe) initiative of the European Commission. The study presented in this paper is based on the work carried out within the Catchment Characterisation and Modelling (CCM) activity of JRC's EuroLandscape Project (now part of the Agri-Environment Action of the Soil and Waste Unit of the Institute for Environment and Sustainability - IES, for the development of a European-wide database of drainage networks and catchment boundaries. The aim of the CCM project is the development of algorithms for the analysis of Digital Elevation Models (DEM) and ancillary data in order to produce a pan-European database of river networks and catchment boundaries at a mapping scale of 1:250,000 to 1:500,000, using highly automated processing tools. Version 1.0 of the database is available, covering the area from Scandinavia to the Mediterranean and from Portugal to 38 degrees Longitude East.

3. The critical contributing area and headwaters

A central question in all studies dealing with the extraction of rivers from DEMs is the location of the channel head. Analyses at the field scale show that related processes are very complex. In general terms, however, a channel head is located where linear fluvial processes start to dominate over diffuse slope processes. Depending on the prevailing geomorphic processes, this condition may be met at a variety of scales, which means that the drainage area for a channel head can vary to a large degree, depending on local conditions [1], [8].

When deriving drainage networks from digital elevation data, the spatial resolution of the DEM is the key characteristic, determining the level of detail at which geomorphic processes can be inferred from the DEM. Using DEMs of high spatial resolution, detailed information on hill-slope processes and channel formation can be derived. At coarse grid resolutions (> 100 m), detailed geomorphic processes and channel initiation cannot be modelled. As an alternative, particularly for studies covering extended areas, a critical contributing area can be defined for deriving the approximate position of channel heads [6], [11], [10], [5], [12], [3].

This critical contributing area can be derived from the analysis of the relationship between contributing area and local slope. If values of local slope versus contributing area for each grid cell are plotted, a graph of the so-called scaling response can be determined (Figure 1). On this graph characteristic changes in the scaling response can be identified, corresponding to changes in the dominance of the prevalent processes.

In particular, two points are interesting for defining channel heads:

(a) the point where dS/dA turns from positive to negative, indicating the critical contributing area corresponding to the change of dominance form hill-slope to fluvial processes, and

(b) the point where dS/dA becomes stable, identifying the value of critical contributing area above which all points are channelised. Point (a) is detectable only when the DEM grid cell size is smaller than approx. 30 m. Point (b) can still be identified from coarse DEMs.

Given the extent of the area covered by CCM and the 250-meter grid cell size of the available DEM, the analysis of the local slope – contributing area relationship for deriving the critical contributing area was the evident choice. In order to overcome the drawback of using a single critical contributing area for all of Europe, representing a large variety of landscapes with highly varying drainage densities, a landscape stratification has been elaborated, and for each landscape type a dedicated critical contributing area was derived from the analysis of the corresponding local slope – contributing area plot.

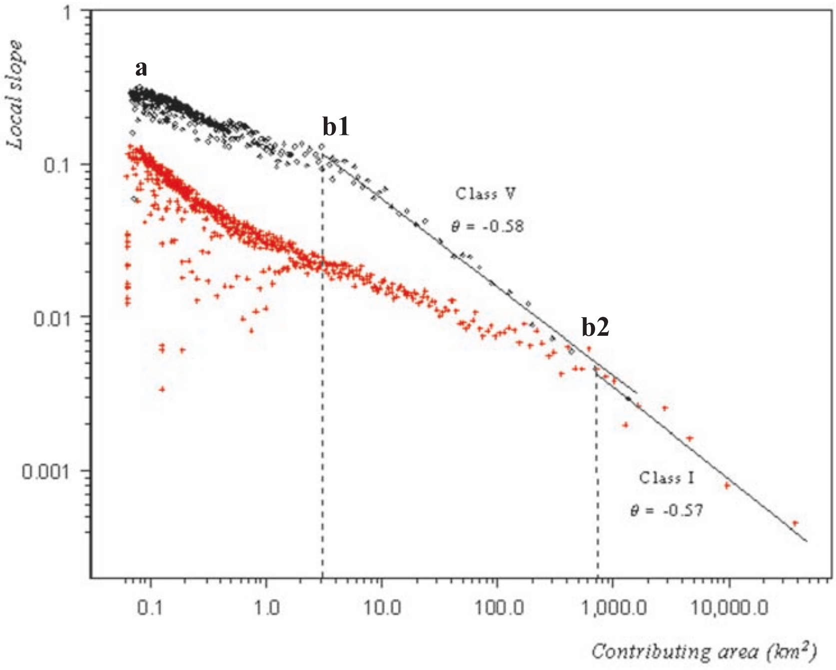

Figure 1. The local slope plotted versus contributing area in logarithmic scale.

In order to elaborate a suitable landscape stratification, five variables have been identified on the basis of a literature survey as the most important factors governing drainage density: relief type, vegetation cover, soil transmissivity, rock erodibility, and climate. Each variable has been classified into three to seven classes and a Landscape Drainage Density Index has been derived from a weighted combination of these variables, using a multi-criteria evaluation technique [16]. In short, the variables have been parameterised following:

- Relief type has been considered through relative relief, defined as the maximum altitude difference in a moving window of 3 by 3 grid cells [9], [13].

- The percentage vegetation cover was derived from CORINE land cover data with a grid cell size of 250 m, reclassified in 14 classes to which an average value of yearly surface cover was assigned on the basis of the scheme derived for Europe by Kirkby [7].
- As a proxy indicator of soil transmissivity, soil texture was selected as the main soil factor affecting channel initiation [2], [15]. Soil texture was derived from the Soil Map of Europe [4].
- Rock erodibility was estimated according to the Gisotti's scale based on the parent material as given in the Soil Map of Europe.

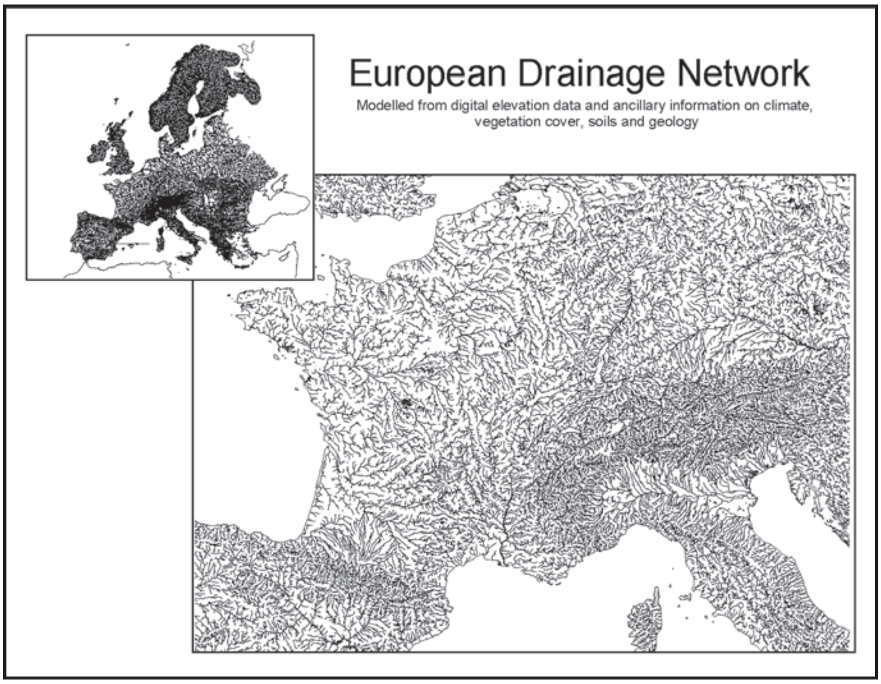

Figure 2. European Drainage Network as derived by the CCM project.

The climate factor was synthetised by the mean annual precipitation, derived from the daily meteorological database of the European MARS project, covering the period 1977-1999 on a 50 km grid [16], [14]. A critical contributing area has then been assigned to each landscape class by analysing the specific relationship between local slope and contributing area and identifying point b in the corresponding plots. This analysis resulted in critical contributing areas varying from a few square kilometres to a few tenths of square kilometres that is, in fact, a stratification of Europe with direct reference to the size of headwater areas.

4. Mapping of European headwaters

An example of the river network resulting from the described methodology is represented in Figure 2. Due to the underlying landscape stratification, it reflects the natural variability in drainage density. Starting from the points identified as channel heads, all down-slope river cells can be mapped. Interim processing results (e.g., flow accumulation and flow direction grids) allow for reversing the mapping process so that cells draining towards the channel head can be identified and headwater areas can be mapped.

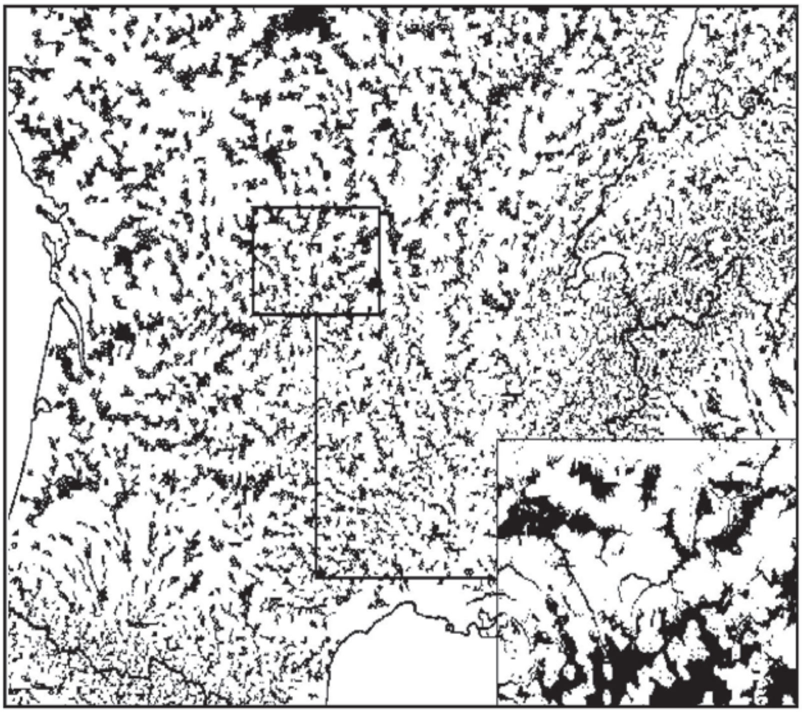

Figure 3. Headwater areas in south-western Europe, extracted from the CCM database.

A resulting map of headwaters in a part of south-western Europe is shown in Figure 3. It must be stressed that from a 250-meter resolution DEM not all headwater areas can be mapped. In our study only headwater areas larger than 1 km^2 are reported. On the other hand, sometimes very large areas are mapped as headwaters. This is due to the fact that the critical contributing area can be quite large, especially in flat areas such as the north European continental planes. In such areas headwaters with a surface as large as 50 to 60 km^2 may be mapped. As a result of this analysis over the entire mapped area, a total surface of about 6,500,000 km^2, 27% or 1,750,000 km^2 have been assigned to headwater areas

5. Wetlands in headwater areas

The main homogeneous source of data on land cover for Europe is CORINE Land Cover (CLC), a data layer realised by the European Commission in the frame of the CORINE programme (Co-ordination of Information on the Environment). The principal sources of information are Landsat Thematic Mapper images recorded in 1985-1994, that have been analysed using photo-interpretation techniques. Given the resolution of the images (10 to 30 m pixel), a minimum mapping unit of 25 ha and a minimum width of 100 m for linear elements have been retained. The CLC legend is hierarchically structured in three levels, with 44 classes in the most detailed level.

At level 1 a main class "wetlands" exists, that is sub-divided at level 2 in "inland" and "coastal" wetlands. At level 3 inland wetlands (defined as *"Non-forested areas either partially, seasonally or permanently waterlogged; the water may be stagnant or circulating")* are further detailed into inland marshes and peat bogs, and it is on these two classes that the attention has been focused.

Inland marshes are defined as "Low-lying land usually flooded in winter, and more or less saturated by water all year round. Marshes may be made up of river ox-bows, areas in which waterways shift from their course, depressions where the ground water table reaches the surface permanently or seasonally, or basins where run off or drainage water accumulates ".

The peat bogs are defined as "Peat-land consisting mainly of decomposed moss and vegetable matter. May or may not be exploited – peat-bogs are peaty ecosystems populated by hygrophilous plants and developing either in flooded hollows in plains (lowland bogs, raised or flat) or at altitude in very rainy countries (blanket or sloping upland bogs).

Under the effect of biochemical and mechanical factors, the accumulated vegetal mass is transformed into a compact, combustible matter made up of over 50% carbon: peat. To qualify as a peat-bog, the accumulated deposits must contain at least 30% organic matter if they are argillaceous and at least 20% in all other cases, and must be more than 40 cm thick. Peat-bogs will remain active (produce peat) for as long as the water supply remains adequate. Any water shortage will kill them. Both categories - active bogs and dead bogs - can be exploited".

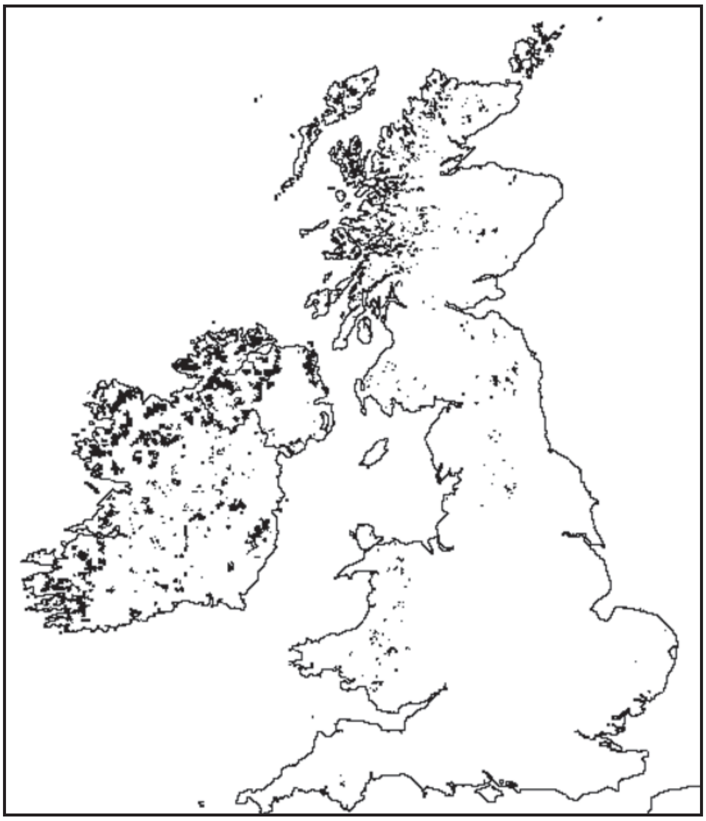

Figure 4. Wetlands in headwaters in Ireland and the UK.

Given the size of the minimum mapping unit, it is evident that a class like wetlands is underestimated in the final assessment because it is often characterized by objects smaller than 25 ha. It is known that this is a drawback affecting many of the "water" classes in the CORINE classification.

The following assessment has been carried out on the area covered by CORINE data, covering the EU15 Countries (excluding Sweden) plus Poland, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, Bosnia and Herzegovina, Albania, Macedonia, for a total of 4,650,000 ha.

Inland wetlands cover some 36,000 ha in this area, that is, less than 1% of the total surface. For the same area, headwaters amount to 1,000,000 ha, and wetlands in headwaters to 10,600 ha, which is about 1% of the headwater area. Figure 4 shows the wetlands in headwater areas in Ireland and the UK, mapped with the described methodology.

6. Conclusions

This paper describes the first approach to wetlands mapping in headwater areas at the continental scale. The process of mapping can be further developed by deeper characterizing the identified areas, for example by assigning them to corresponding drainage basins, altitudinal areas, landscape or administrative units. The results are based on the data available. Updating and improvement will be possible in the short term with the delivery of the new CORINE 2000 system (based on satellite images acquired between 1999 and 2001) and using more detailed Digital Elevation Models (e.g. Shuttle Radar Topography Mission).

It has been clearly stated that the limits of the approach are due to the resolution of data. In fact, at this scale, isolated wetlands below the 25 ha threshold or even complex systems of small elements are neglected; it is clear that a more detailed approach is needed for the management at the medium/large scale.

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THE ROLE OF FOREST ON THE HYDROLOGY OF HEADWATER WETLANDS

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KEYWORDS / ABSTRACT: Forest hydrology / headwater wetlands / Japan

The worth of forest coverage is discussed by the comparison of both devastated and well-grown forested headwaters through sediment yields, flood control function, water budget and heat budget. Many hydrological and micro-meteorological observations from slopes to headwaters have been carried out in Japan, at hilly mountain underlain by weathered granite and other geology. In order to analyze the observed data and to explain the results, needed models have been developed. Finally, it has become clear that the worth of forest coverage emerges 50-60 years after initial reforestation. In headwater wetlands, the knowledge attained is effective for the explanation of the role and the planning of conservation.

1. Introduction

Whether headwater area has a wetland or not is determined climatically by the balance between precipitation and evaporation. Potential evaporation amount corresponds to the condition when the resistance of land surface is zero (by Penman-Monteith's equation [21]), represented by evaporation on shallow open water or wet grass land without trees. Generally, factors controlling evaporation are energy balance, air temperature, vapor water, wind velocity and physiology of vegetation. As energy balance and air temperature have a tendency to decrease in higher latitude regions compared to lower latitude regions, there are many wetlands at high latitudes. Otherwise, wetlands are seen in areas of high altitude in middle latitude regions and in tropical rainforest regions. In Japan, headwater wetlands are located at rather high altitude in mountainous area. A special feature of wetlands in Japan is abundance in

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Environmental Role of Wetlands in Headwaters, 17–47.

rare species of grasses, insects and animals. Migratory birds are sometimes seen, in the case of remote area, far from human living areas. Some areas are now in crisis due to the invasion of humans, because these lands are able to be changed to agricultural fields by reclamation and drain works. In this chapter, the hydrological role of headwater wetlands is discussed by the comparison between forested and devastated headwaters.

2. Sediment yield

2.1 GENERAL REMARKS

Headwaters are thought to be important and essential areas for producing safe and stable water, not only as irrigation supply but also as a drinking source for people living downstream. Recently, we have realized that these areas have another worth in maintaining diversity of biosphere and humans have started to be aware of this real meaning. Developed countries never paid attention to this worth until the end of the 18th century, and developing countries have begun to understand this worth nowadays. The increase, however, of human population and the demands of food production have made the situation difficult. Nevertheless, the environment of source areas has to be maintained with natural vegetation with long-life view in the eco-hydrological aspect.

2.2 SEDIMENT YIELD IN DEVASTATED HEADWATER AREA

The Lake Biwa, located in central Japan, is the largest lake of Japan with 670km^2 in area. South of the lake, the Tanakami mountain range is situated, which was devastated by heavy use as supply areas for wood, fuel and fertilizer of forest production situated close to villages in the 19th century. Another reason contributing to the devastation is that the Tanakami Mountaions are underlain by weathered granite and easily eroded soil, as the particle size is rather small and loose. As it supplied a great volume of sediment downstream, disasters due to flood and sediment deposit attacked villages downstream. Since the beginning of the 20th century, conservation works of headwater areas began in the source area of large rivers with big cities downstream. As the river water of Lake Biwa flows down to Osaka, Kyoto and Kobe city, the Tanakami Mountains became an objective area for conservation works. The conservation works are separated into two parts. One is hillslope works aimed at the fixation of soil by reforestation with mainly pine tree species mixed with other plant species able to fix air nitrogen as fertilizer. The other is check-dam works on the river bed aimed at the prevention of riverbed scoring. In order to evaluate these effects, various kinds of investigations and observations were carried out in the Tanakami Mountains.

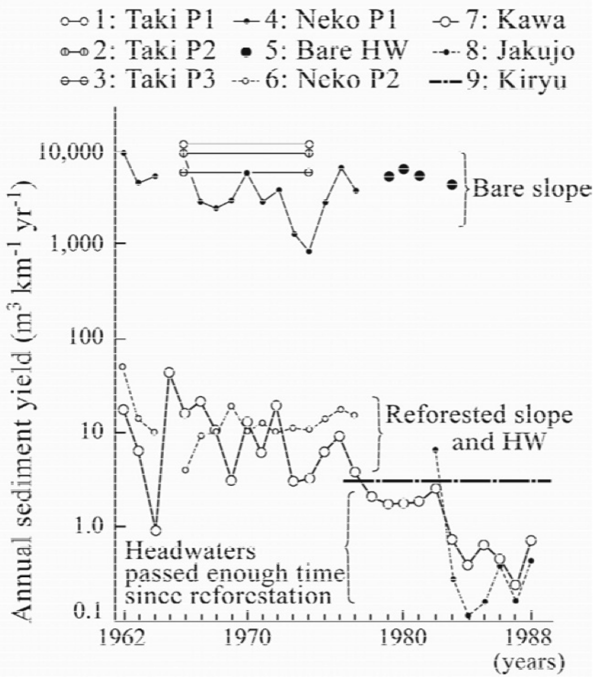


Figure 1. The inter-annual change of sediment yield between bare and reforested area observed in the Tanakami Mountains (granite massive in Central Japan), [27].

2.3 SEDIMENT PRODUCTION AND TRANSPORT

Generally, sediment yield has been observed by following methods:

1) peg method at a slope
2) trap method at a slope or source area

Figure 1 shows clearly that annual sediment yields at bare slopes are almost in the range of 5,000 to10,000 $m^3km^{-2}yr^{-1}$ despite the difference in method, and that the sediment yields from reforested slopes show almost 10 $m^3km^{-2}yr^{-1}$. The decrease is equal to two to three orders lower than that for bare slope. Furthermore ‚sediment yields of headwaters that have passed enough time since reforestation show 5.0 to 0.1 $m^3km^{-2}yr^{-1}$, which is equal to a one to two order decrease from that for the recently reforested slope. For this process, the fixation of riverbed by the construction of check-dams seemed to be effective.

Why has such a big difference in the sediment yields occurred among the different types of land coverage? From individual investigations and observations concerning erosion processes, it was clarified that movable soil material was produced on the bare slope by weathering and frost action, and those materials were transported downstream by the tractive force of hydraulics during each flood event [26], [34].

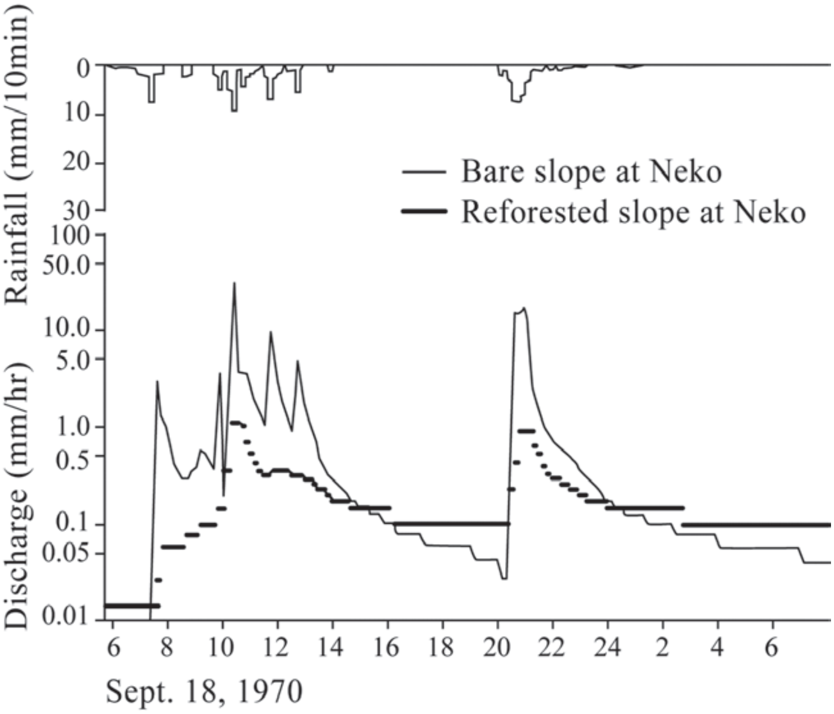


Figure 2. Comparison of flood hydrographs observed at bare and reforested plots at Neko (the Tanakami Mountains, Central Japan), [34].

Figure 2 shows an example of a flood event with two occurrences of heavy rainfall exceeding 10mm/10min in intensity within one day at adjacent plots with both bare and reforested slopes at Neko, Tanakami Mountains. The hydrograph for the bare plot has a peak flow of over 40 mm/hr in both the first and the second cases, but the hydrograph for the reforested plot has a peak flow of only 1mm/hr in both cases. This means that the effect of reforestation was to decrease the peak flow by one-fortieth. By this reason, it is clear that sediment transport amount has decreased remarkably as shown in Figure 1. Now, we have already recognized that sediment yield has close relationships with flood discharge. Quantitatively, what relationships are adequate to explain this? Mayer-Peter and Müller [19] developed sediment hydraulics for application to mountain torrents. Their equation is written as follows:

$$\frac{q_b}{\sqrt{(\delta/\rho-1)gd^3}}=8\left[\frac{U_*^2}{(\delta/\rho-1)gd}k-\Psi_c\right]^{3/2} \text{————————————————}(1)$$

where, q_b is the bed load rate in volume per unit time and unit width, δ and ρ are the specific weight of sand and water, respectively, g is the gravitational constant, d is the mean diameter of the bed load materials, U_* is the shear velocity $[=(gHS)^{1/2}]$, H is the depth of water, S is the channel slope, k is the ratio of effective energy, and Ψc is the critical tractive force ($\Psi c=0.047$).

Otherwise, for rivers the regime theory between the flow rate, Q(m^3/sec) and the width of the cross section of river, B (m) is estimated by investigations, as follows:

$$B=\alpha\cdot\sqrt{Q} \text{——————————————————————————}(2)$$

where, α is a parameter. Manning's roughness, n is assumed as n=0.02 by the particle diameter of bed load materials and the α value was assumed as 0.4.

Finally, the relationships between river discharge and the sediment concentration in slopes and torrents of the Tanakami Mountains is explained in Figure 3. This figure shows that the amount of sediment transport is controlled by flow rate and slope angle in both riverbed and slope with the same particle size. Whether the riverbed is scoured or deposited is determined by this relationship. Particularly, it is important to recognize that the angle of slope or riverbed of S=0.4 shows a high sediment concentration close to almost five percent when flow rate exceeds $10^{-3}m^3$/sec.

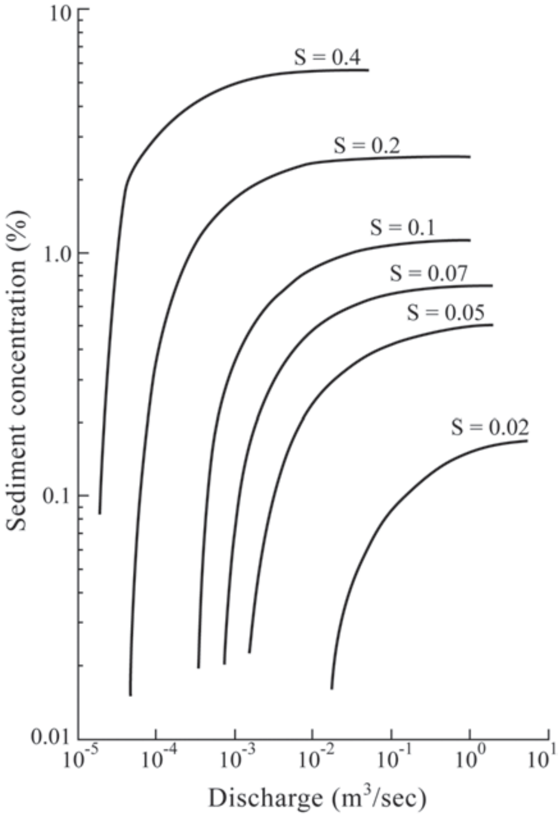


Figure3. The relationship between river discharge and sediment concentration in the Tanakami Mountains (S: angle), [26].

3. Flood flow and forest coverage

3.1 SEPARATION OF FLOOD RUNOFF

Though sediment transport was shown to be controlled by flood runoff in Section 2.3, it needs to be explained what kinds of factors affect the formation of the flood runoff. Basically, rainfall falling in headwater areas becomes both infiltration and surface flow. The infiltration rate is generally low on bare surfaces and high on land surface covered by vegetation. The infiltrated water turns to sub-surface flow along A and A_0 layers of the soil. Deeply percolating water reaches the bottom of the soil, that is, the surface of bedrock. Usually, such water flows down to the open channel along the slope as ground water flow. Though some parts of ground water percolate vertically along rock cracks, the amount is usually negligible in mountainous area composed of old sedimentary rock such as the Paleozoic except for limestone, and plutonic rock such as granite.

The whole headwater area may be categorized as two parts: slope system and open channel system. Both surface flow and sub-surface flow in the slope system are called direct runoff or quick flow. The other runoff components are called base flow or delayed flow.

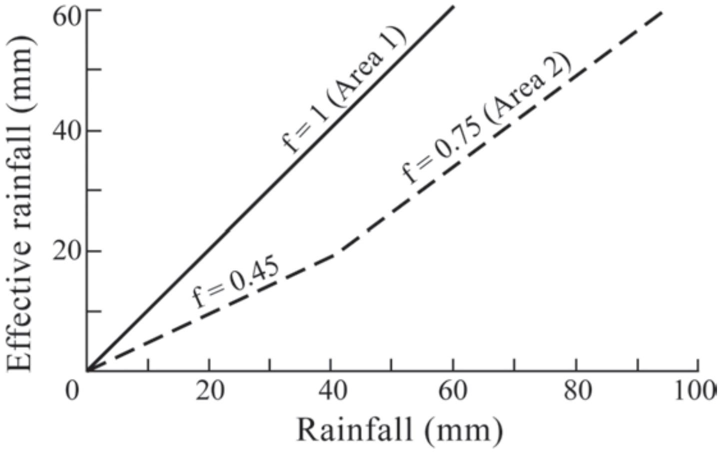


Figure 4. Relationships between rainfall amount and effective rainfall (direct runoff) (Fukushima, 1981).

Flood runoff is defined as the component of the upper part separated by a straight line from the standing-up point until the arriving point with the same constant recession curve on the hydrograph in each headwater basin. Hewlett and Hibbert [14] proposed the separation method in which base flow increases at a constant ratio from the standing point on hydrograph by statistical analysis, which seemed to be the common understanding among headwater hydrologists. Though this separation seems easy if comparatively large floods with a single peak are sampled, it is not such an easy task in practice for flood events implying small rainfall intensity or with double peaks. Nevertheless, the separation of the direct runoff component by many flood events is possible. In order to estimate a flood hydrograph, the effective rainfall intensity should be defined. For this, we could use two basic ideas: Horton's infiltration theory [12], [13] or the idea of variable source area [4]. The author avoids the argument about which is better in this section, but, it is possible to estimate effective rainfall intensity from the relationships between the cumulated rainfall amount and the estimated direct runoff shown in Figure 4. The dotted line shows a typical example for separation. Apparently, the ratio of the direct runoff component increases with rainfall amount.

3.2 FORMATION OF A HYDROGRAPH IN A HEADWATER AREA

Flood hydrographs generally seem to change in shape according to basin scale, slope and torrent gradient in addition to the difference of forest cover. By using the kinematic wave method, the topographical difference of all the headwaters can be explained as the differences of slope length and gradient, and channel length and its gradient as shown in Figure 5.

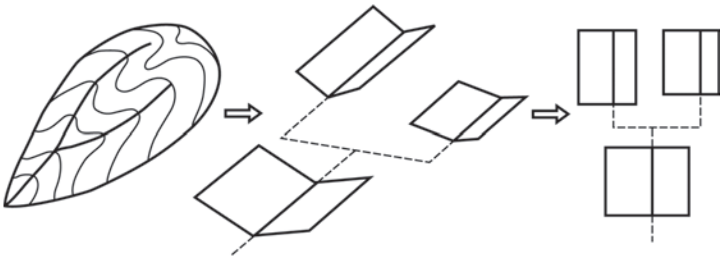


Figure 5. Topographical modeling on the kinematic wave method [5].

How can we show the differences of forest coverage on the models shown in Figure 5? One attempt is the parallel slope model developed by Fukushima [5] (Figure 6). The parallel slope model defines that all of a slope has two components. One is impermeable slope without soil and the other is permeable slope with forest soil. The first is named as Area 1 and the second as Area 2. The ratio of Area 1 is defined as C, and the ratio of Area 2 is 1-C in the whole headwater, as shown in Figure 6. The vertical axis of figure 4 shows direct runoff and is assumed as a trace of effective rainfall in time series, now. The difference of basin scale can be explained from the difference of channel length and its gradient, as shown in the example in Figure 7.

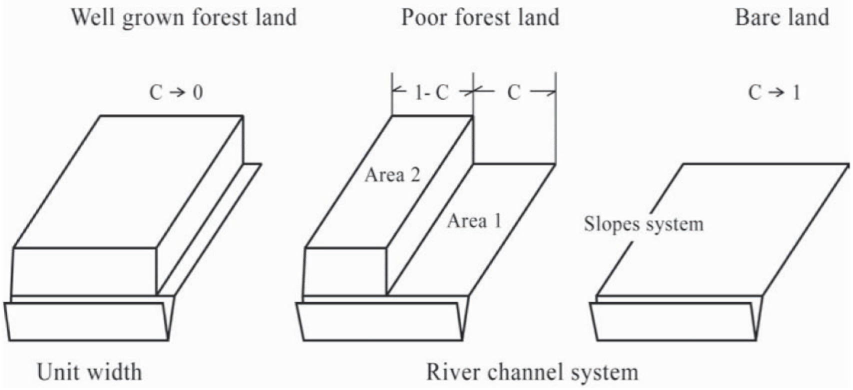
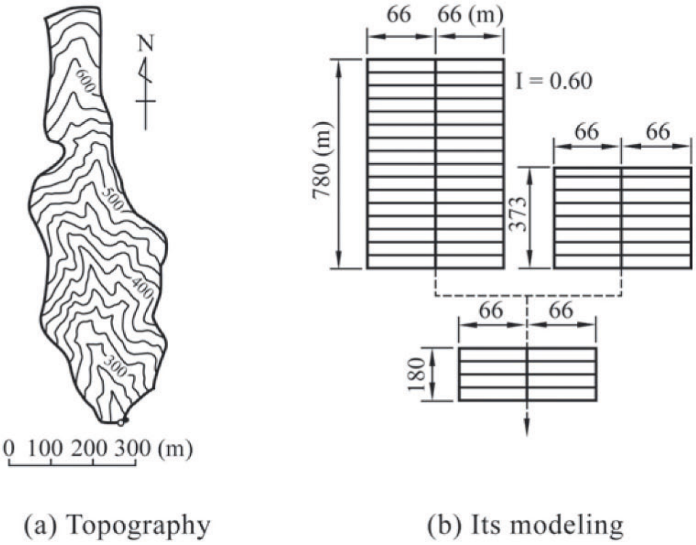


Figure 6. The parallel slope model developed by Fukushima [5].



(a) Topography

(b) Its modeling

Figure 7. An example of topographical modeling [5].

This proposed model is based on the assumption that well-grown forest is rich in forest soil while a devastated mountain is poor in forest soil. Such effects are apparent in the relationships between rainfall amount and direct runoff shown in figure 4, first, and in quickness of rainwater movement, second.

This may be written as the following equations:

For the slope system,

$$\frac{\partial h_1}{\partial t}+\frac{\partial q_1}{\partial x}=\Omega\, r_{e1} \quad \text{------------------------------}(3)$$

where, h_1 is the depth of water, $q_1$is discharge rate in unit width, t and x are time and distance, Ω is a constant on unit exchange, and re_1 is effective rainfall intensity in Area 1 with the ratio of C.

$$\frac{\partial h_2}{\partial t}+\frac{\partial q_2}{\partial x}=\Omega r_{e2}, \quad \text{------------------------------}(4)$$

where, h_2 is the depth of water, $q_2$is discharge rate in unit width, t and x are time and distance, Ω is a constant on unit exchange, and re_2 is effective rainfall intensity in Area 2 with the ratio of 1-C.

The motion between h and q is assumed on the kinematic wave method as follow:

$$h=kq^{p} \quad \text{------------------------------------}(5)$$

where, k and p are parameters, respectively.

If water flow in the slope system is approximated as surface flow, the following relationship can be applicable for Equation (5) by Manning's law,

$$k=\left(\frac{N}{\sqrt{I}}\right)^{p}, p=\frac{3}{5} \quad \text{------------------------------}(6)$$

where N represents the equivalent roughness and I is the gradient of slope(sinθ).

If water flows through soil particles in forest soil, Darcy's law can be applicable as follows:

$$k=\left(\frac{\gamma}{MI}\right)^{p}, p=1 \quad \text{------------------------------}(7)$$

where γ is the porosity of forest soil and M is the permeability of Darcy's law.

For the channel system,

$$\frac{\partial A}{\partial \imath}+\frac{\partial Q}{\partial x}=Cq_1+(1-C)q_2 \tag{8}$$

where A is the cross profile of channel section and Q is river discharge.

$$A=KQ^{p} \tag{9}$$

where K and P are parameters, respectively.

$$R=K_1A^{Z} \tag{10}$$

where R is channel radius, K1 and Z are parameters, respectively.

Finally, the following equation is assumed as Manning's law.

$$K=\left(\frac{n}{K_1^{2/3}I^{1/2}}\right)^{P},P=\frac{3}{2Z+3} \tag{11}$$

where n is Manning's roughness.

After the parallel slope model was applied to many flood events occurring in these headwater basins, parameters controlling the motion of water flow were determined. For the channel system, the following parameters seemed acceptable when comparing field measurement and model fittings (Table 1).

The area of the headwater basins ranges from 0.05 to 0.5 square kilometers. They are underlain by granite and Paleozoic geology. Parameters controlling water flow in the slope system were plotted in relationship between the slope angle and the equivalent roughness, K_2 in Area 2 (Figure 8). It is clear that K_1 in Area 1 is just 0.1 times that of K_2. This shows that the C value can be useful for the evaluation of forest.

Basin name	P	K
Kiryu main	0.77	3.0
Kiryu sub2	0.77	3.0
Jakujo	0.77	3.0
Yayoi	0.77	2.0
Kawa main	0.7	1.0
Hachi	0.7	1.0

Table 1. Parameters controlling channel flow.

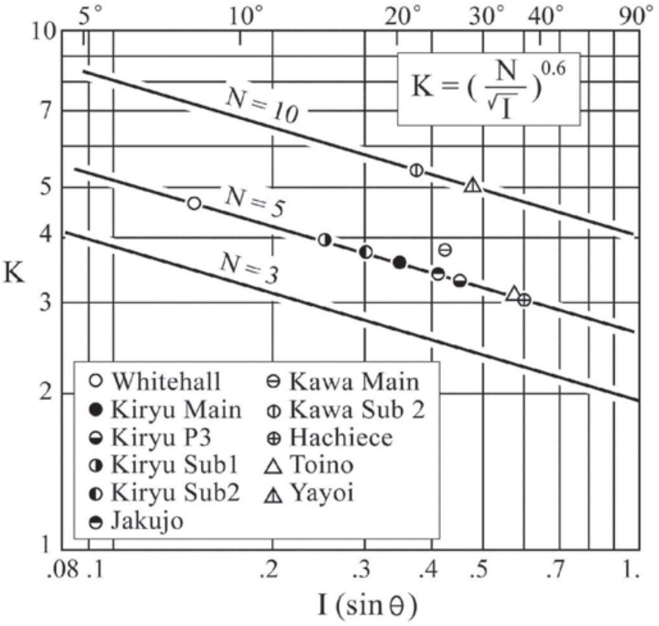


Figure 8. Relationship between slope angle and equivalent roughness, K.

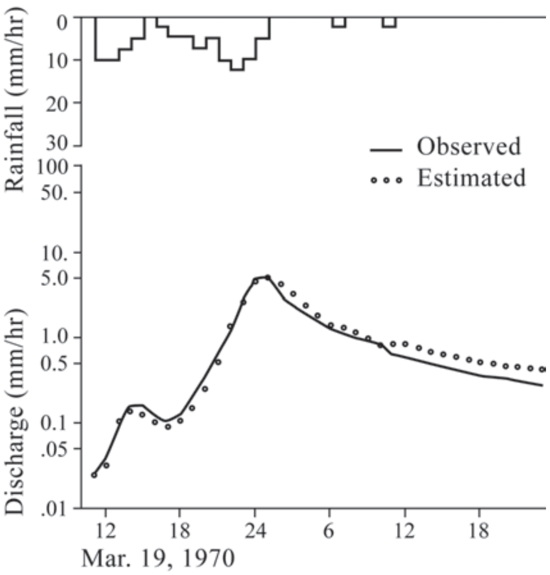


Figure 9. An example of estimated hydrographs in the Whitehall headwater.

In Figure 9, the data for the Whitehall headwater were provided by Prof. J.D. Hewlett. This headwater is famous being used for explaining the concept of variable source area by Chorley [3, cf. 35]. The reason why the author applied it for the validation is that it has gentle slopes compared with the Japanese headwaters observed previously. Anyway, it is very important that the equivalent roughness in the forested slope can be explained as values of 5-10, whether its angles are either steep or gentle in the slope system.

4. Forest coverage and Water yield

4.1 EFFECTS OF FOREST COVERAGE ON WATER YIELD

Since the beginning of the 19th century, a lot of experimental studies have used paired watershed methods for the clarification of forest coverage to water yield in many countries. Finally, Bosch and Hewlett [2] synthesized the results reported from most research groups. It shows that the annual increase of water yield in a headwater area is proportional to the cutting ratio of forest coverage, and that the increasing ratio of water yield is the highest in evergreen coniferous forest, next highest in deciduous road-leaved forest and low in bush forest. Thus, the trends are similar in spite of the difference in rainfall amount.

How much does it change in time series of the same headwater? By using long-term experiments, Swift and Swank [33] clarified that water yield is much higher just after clear-cutting and decreases gradually with reforestation. As an example of the effect of reforestation on water yield, Schulze and George [25] have analyzed the observed data in South Africa and show that annual evaporation amount quickly increases just after reforestation (in comparison with a short grass used as a control site); during some 10-20 years after reforestation. The peak seems to correspond with when the leaf amount reached saturation. Thus, experiments assume the following equation.

$$P = Q + E + \Delta S \text{———————————————————————————} (12)$$

where P is precipitation, Q runoff, E evaporation and Δ S difference in the water storage.

If the period for the analysis is taken as one year, Δ S is negligibly small. Therefore, the above-mentioned studies used and discussed annual amount, and now, it is easy to understand that an increase in runoff means a decrease by the same amount in evaporation.

Except for the tropics and regions where the effect of snowfall is not negligible, for most countries with a humid climate located in the middle latitudes, the actual evaporation has a seasonal variation. In such areas, the short-period analysis of water budget proposed in [15] can be applied for a small basin with the assumption that the same amount in river discharge has the same water stored in the basin, because the difference of the stored water, Δ S is assumed to be negligibly small when timing of both the beginning and the end is in the range of one and two months. Suzuki [30] has applied this method for ten years of hydrological data in a hilly mountain in Japan and has succeeded in getting the monthly amount of evaporation.

4.2 DEVELOPMENT OF A SYNTHETIC HYDROLOGICAL MODEL

Though we succeeded in understanding the formation system of flood runoff in Section 3.2, additional issues such as direct runoff and evaporation processes remained unresolved. HYCYMODEL [7] was developed and proposed for understanding the hydrological effects of reforestation, quantitatively. It is a kind of conceptual runoff model and has the feature that it takes only seven parameters with time independence in runoff formation system. The structure of HYCYMODEL is shown in Figure 10.

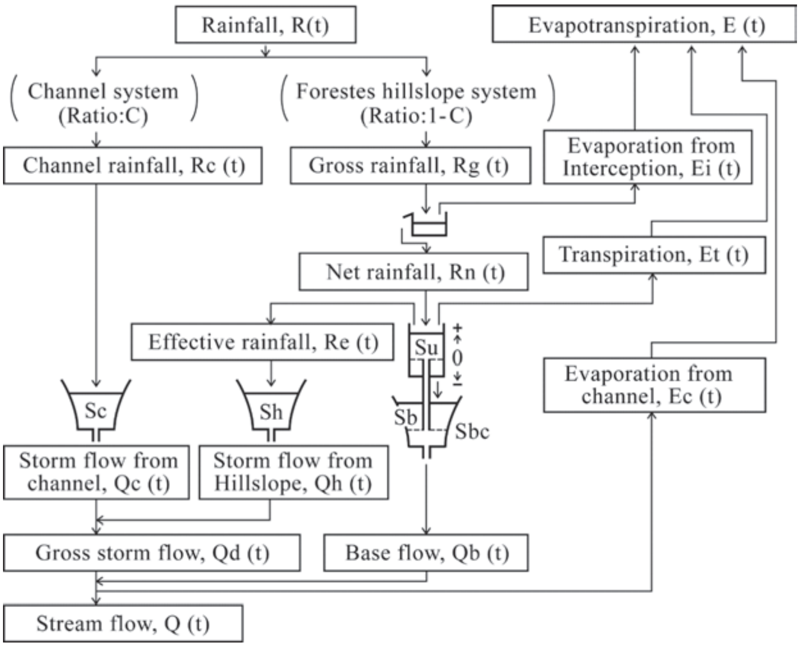


Figure 10. The structure of HYCYMODEL [7].

In Figure 10, C means the area ratio of the impermeable channel. Effective rainfall, Re(t) to the other area except the impermeable channel area is determined by the mean effective soil depth parameter, D_{50}(mm) and its deviation, Dsig. Re(t) is calculated by the following procedure in detail. At first, an apparent storage in the Su Tank of Figure 10, Su'(t) is

$$S'u(t) = Su(t-1) + Rn(t) \quad \text{------------------------------} (13)$$

where Su is storage in the Su-Tank, Rn is net rainfall reaching the ground and t is time step.

The variable for the normal distribution, ξ is

$$\xi = \left\{\log\left[S'u(t)/D_{50}\right]\right\}/D_{sig} \tag{14}$$

here, Dsig is defined as follows

$$D_{sig} = \log(D_{50}/D_{16}) \tag{15}$$

The m value which means the contributing area ratio, can be calculated as the excess probability using the normal distribution.

$$m = \int_{-\infty}^{\xi} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \tag{16}$$

The effective rainfall forming a direct runoff component, Re(t) is

$$\mathrm{Re}(t) = m \cdot Rn(t) \tag{17}$$

The author assumes that effective rainfall occurred from the saturated surface and its ratio varies with the saturated area and rainfall intensity. This may be an assumption close to the idea of Dunne [4].

Otherwise, the relationship between storage S and discharge rate Q in each Tank in Figure 10 are assumed as follows;

$$Sc = KcQc^{06}, Sh = KhQh^{06} \tag{18}$$

$$Su = KuQu \tag{19}$$

$$Sb = KbQb^{01} \tag{20}$$

where Equation (18) is used for the direct runoff component in each channel or hillslope system, Equation (19) is for the change in soil water at the top soil layer, and Equation (20) is for the base flow component. Kc, Kh, Ku and Kb are parameters, respectively. The power of Equation (18) was assumed to be 0.6 by the previous study [5], using the parallel slope model. The motion of surface and sub-surface is approximated by Manning's law. The power of Eq.(20), 0.1, was chosen by the least square error analysis and it satisfies the analysis of saturate-unsaturated flow regime in a slope system [31].

In order to apply HYCYMODEL for actual headwater basins, evaporation, Ei(t), transpiration, Et(t) in slope system and channel evaporation, Ec(t) should be determined. This subject will be discussed in section 4.3.

Finally, the direct runoff component, Qd(t) is written as follows;

$$Qd(t)=C\cdot Qc(t)+(1-C)\cdot Qh(t) \qquad \text{-----------------------}(21)$$

Evaporation component, E(t) is written as follows;

$$E(t)=C\cdot Ec(t)+(1-C)\cdot\left[Ei(t)+Et(t)\right] \qquad \text{------------------}(22)$$

In summary, HYCYMODEL has only seven time-independent parameters such as C, D_{16}, D_{50}, Kc, Kh, Ku and Kb and it can be used for short-term flood events to long-term runoff analysis.

4.3 APPLICATION OF HYCYMODEL TO A SMALL HEADWATER AREA

HYCYMODEL was applied in the Kiryu experimental basin (a small headwater basin in a granite massif). The area of 5.99 ha is covered by pine and cedar which has passed almost eighty years since its reforestation. It has reliable stream flow and rainfall data for ten years at hourly time intervals, and the parameters controlling evapotranspiration have been investigated and determined.

At first, the monthly mean evapotranspiration amounts were estimated by the short-term water budget method [30]. Secondly, the relationship between rainfall intensity and rainfall interception was modeled in one hour intervals by field investigations and analysis [29]. The rainfall interception component has been shown to be non-negligible in humid mountainous areas [7]. The rainfall interception model developed by Rutter et al. [24] has been generally used for the forest canopy [10], [11]. Suzuki [30] considered that the monthly mean evapotranspiration minus the monthly mean rainfall interception calculated by the model equals the monthly mean transpiration. The bold solid line in Figure 11 shows the monthly mean distribution of transpiration estimated in Kiryu experimental basin by Suzuki [30]. In HYCYMODEL, the obtained monthly mean transpiration is taken as the monthly potential transpiration rate, $e_p(i)$, at first. Actual transpiration is controlled by Sb amount. Then, the model assumes the critical storage to restrain transpiration, Sbc.

So, the actual transpiration is estimated by the following rule. If Sb>Sbc

$$Et(t) = ep(i) \quad \text{------------------------------------}(23)$$

If Sb<Sbc

$$Et(t) = ep\,(t) \cdot Qb(t) / Qbc \quad \text{---------------------------}(24)$$

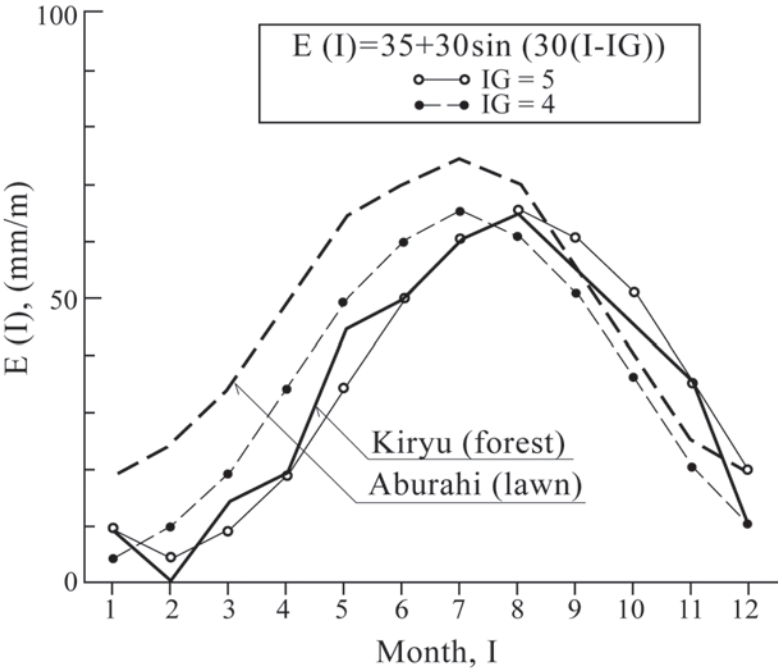


Figure 11. Approximation of transpiration in different land surfaces from the estimates of monthly transpiration determined at the Kiryu basin [8].

The model of rainfall interception is rather complicated, but the concept is not so difficult. It is a transformation system from the gross rainfall, Rg(t), to the net rainfall, Rn(t), in HYCYMODEL. Generally, the maximum storage for canopy and trunk and its evaporation rate were assumed as 1.97mm and 0.162mm/hr in Kiryu, respectively. Nowadays, the evaporation rate for wet canopy can be estimated by Penman-Monteith's equation, but the parameter of the maximum storage is still not so simple because it has no direct relation to leaf-area index. The monthly value of the evaporation rate in a channel system was represented by using the same rate of the transpiration in Kiryu because the C value of 0.035 is rather small. Though the author has considered the restraining effect of transpiration by using Qbc, it became clear that its effect is small in the temperate-humid climate of Kiryu.

The sequential estimation of hourly stream flow during ten years has corresponded in good agreement with that observed, as it confirmed not only long-term runoff, but also short-term flood runoff. In addition, the change of base flow seems rational and the effect of the antecedent rainfall can be explained as the change of storage of water in a basin [7].

Figure 12 shows the relationships between cumulated rainfall and direct runoff with different rainfall intensities. This result means that direct runoff amount is highly controlled by rainfall intensity and cumulated rainfall amount. As a result, the rainfall type continuing for a short time with high intensity or continuing for a long time with lesser intensity may request different countermeasures.

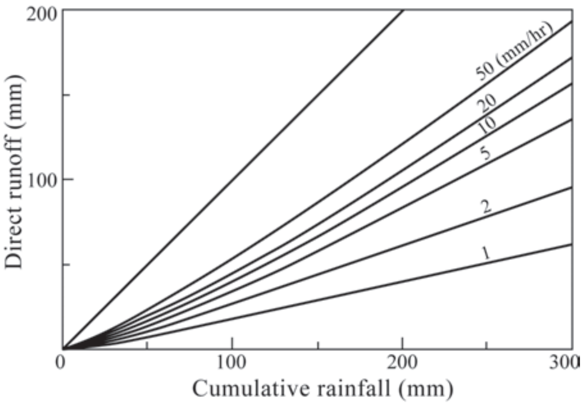


Figure 12. The relationships between cumulated rainfall and direct runoff estimated by different rainfall intensities [7].

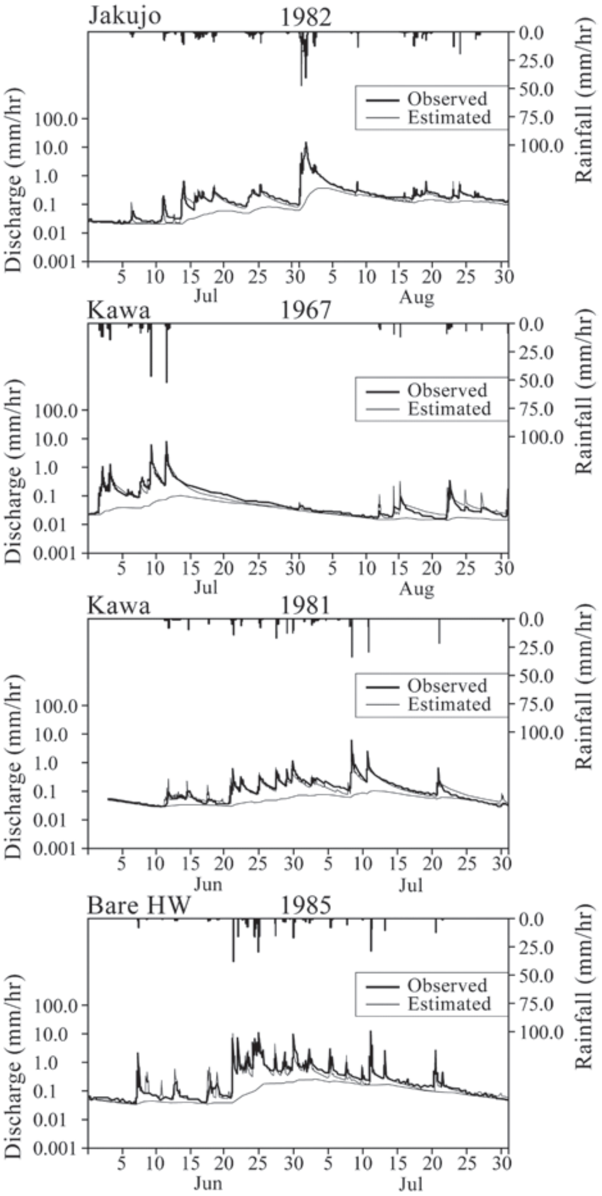


Figure 13. Hydrographs estimated in daily intervals, from sites with different dates of reforestation (the Tanakami Mountains, Japan) [6].

4.4 EVALUATION OF REFORESTATION WITH HYCYMODEL

The values of the HYCYMODEL parameters were determined by application to the observed hydrographs chosen from six mountain small headwater basins which were located within the same granite mountain and had different lengths of time since the reforestation was done, shown in Figure 13. The dark white lines in each hydrograph show the lines of base flow estimated.

The fitting work was done using twenty minute to hourly and daily data because C, D_{16}, D_{50}, Kc, Kh and Ku depend on quick flow components, and Kb is easy to determine from long-term data showing recession curve on hydrographs. The transpiration rate was approximated in each basin, using the trigonometric function shown in Figure 11. The function is as follows;

$$Et(t) = Delta\left\{35+30\sin\left[30\ (I-IG)\right]\right\} \qquad ----(25)$$

where I is the month represented by 1-12. Therefore, the parameters controlling the transpiration rate are Delta and IG.

The decrease from the gross rainfall, Rg(t) to the net rainfall, Rn(t) is an effect of the rainfall interception. After the intercepted rainfall in each basin was estimated by hourly data, it was converted to daily data as shown in the following function:

$$Rn(t) = AG\cdot Rg(t) - AI \qquad ---------------------------(26)$$

where AG and AI are parameters estimated by hourly application.

The results obtained by the application for different basins versus the number of years passing since reforestation are shown in Figure 14. The unlisted parameters are just the same as the values obtained in the Kiryu experimental basin [7]. Now, we may be able to attempt the simulation of hydrographs and how much reforestation affects the hydrograph during 100 years, as shown in Figure 15.The hydrograph passing 100 years after reforestation seems to be very mild, but the hydrograph for the bare basin shows a rapid change and wide fluctuation. The inter-annual changes of water balance components, such as evaporation, direct runoff and base flow, are simulated at an interval of ten years after reforestation.

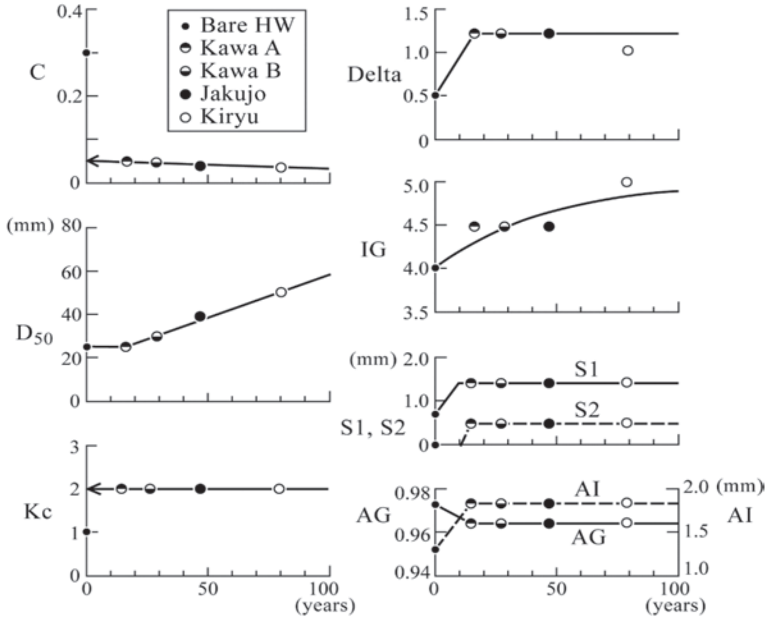


Figure 14. HYCYMODEL's parameters [6]: C, D_{50}, Kc are parameters controlling the time of delay; Delta is the ratio of monthly transpiration; IG is the phase change in the sine function listed in Figure 11; S1 and S2 are parameters related to the rainfall interception of the canopy and trunks, respectively; Ag and AI are also the parameters of interception aggregated to daily intervals, and AI equals the maximum amount of daily rainfall interception and AG is its evaporation rate.

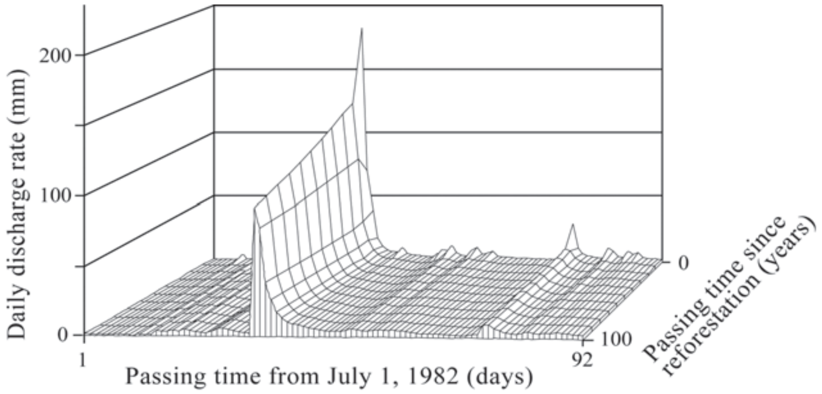


Figure 15. Simulated hydrographs for ninety days showing how the number of years since reforestation affects stream flow over a one hundred-year period, using the same rainfall data and with an interval of ten years after reforestation [6].

The result is shown in Figure 16 as the ratio for rainfall amount. It indicates that the water balance at a devastated basin without vegetation has much larger total runoff that consists of direct runoff and the base flow component, lower evaporation, and that the base flow component is less than direct runoff.

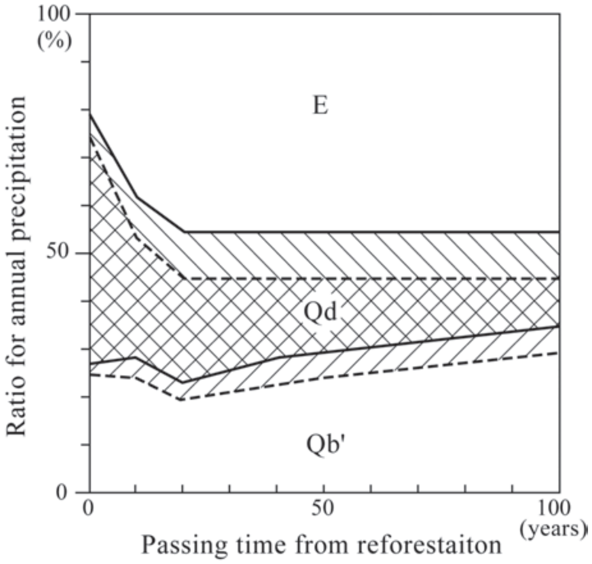


Figure 16. Change of water balance components at different passing years after reforestation. Hatched parts by slant lines are the results of years with much more or less annual rainfall than the mean. (E: Evapotarnspiration, Qd: Direct runoff, Qb': Base flow), [6].

After almost twenty years have passed, evaporation reaches the highest ratio because forest canopy almost completely covers the land surface. The tendency is not changed in years with either much rainfall or less rainfall, as shown by the two kinds of slant lines. Generally, river water of the base flow component in a headwater is clean and is easy to be used for all types of demands. How we could increase the base flow component is an ultimate objective in considering headwater management. Although it is true that a devastated mountain can supply much more water downstream than from a forested area, nowadays all of us recognize that river water from bare land contains 100 to 1,000 times more sediment yield than that from forested areas, as shown in Figure 1. Figure 16 indicates that the ratio of base flow recovers almost 50 to 60 years after reforestation. This means that the value of reforestation should be recognized and supported by those who keep a long-term perspective on sustainable life.

4.5 HYDROLOGICAL EFFECTS ON LAND USE CHANGE

Hydrological differences between a forested mountain and a golf course were investigated at Aburahi basin, in a mountainous area near Lake Biwa (Central Japan), [8]. Hydrological components were separated by the application of HYCYMODEL from the data covering a year. Water budgets in both areas are shown in Figure 17.

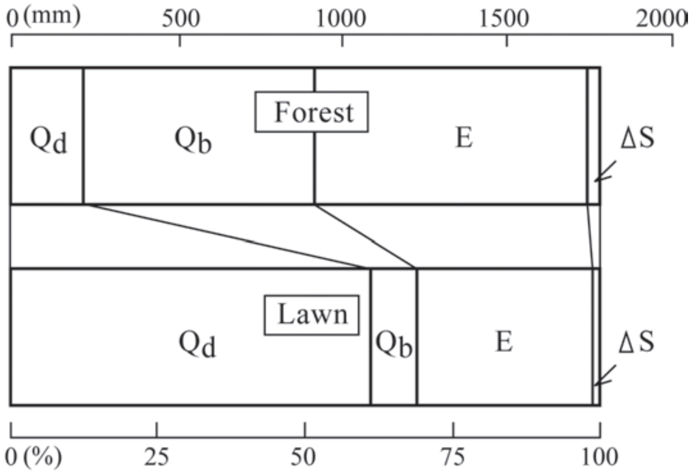


Figure 17. Comparison of Water budgets in forested mountains and in a golf course (Qd: direct runoff, Qb: base flow, E: evapotranspiration, ΔS: changes of storage), [8].

Figure 17 shows that the evaporation amount in the golf course is smaller than that in the forested area, and its amount in the golf course was applicable to the Priestly-Taylor equation [23]. It was applicable due to basic heat components such as radiation balance, wind speed and humidity, not to mention air temperature. If we consider a golf course as a representative of grass-land, this result is understandable. The direct runoff amount in golf course is much larger than that in a forested area. It should also be considered that the golf course has been equipped with a drain network system under the ground in order to be able to continue to play even on a rainy day. In the same period, the rain and stream waters were collected at one-week intervals. The chemical budget attained is shown in Table 2. Except pH, the unit of the other components is given as kg/ha/yr. Table 2 shows that pH of rain water is lower than in the streams, and that chemical components such as N and P are poorer in the stream water than in rainwater. And only these components in the golf course show larger values than in the forested area. It seems that chemical fertilizer is used for maintaining the golf course just as in agricultural fields. But, the other geochemical components seem to be similar in both the forested area and golf course.

Table 2. The input/output ratio of water chemicals (kg/ha/yr).

	R	**Qf**	**Qg**	**R-Qf**	**Qg/Qf**
pH	4.64	7.58	7.43	-	-
SS	-	87.9	84.0	-	0.96
HCO3-	333.5	354.8	-	1.06	
Cl	24.1	48.7	105.6	-24.6	2.17
SiO2 -	64.9	58.6	-	0.90	
SO4 24.7	58.8	173.6	-34.1	2.95	
NH4-N	3.72	0.04	0.05	3.68	1.25
NO3-N	3.27	2.56	3.73	0.71	1.45
Org-N1.08	0.28	3.97	0.80	14.2	
Total-N	8.07	2.88	7.75	5.19	2.69
P	0.546	0.081	1.625	0.465	20.1
K	3.75	10.34	34.15	-6.59	3.30
Ca	4.97	66.65	88.49	-61.68	1.33
Mg	1.40	18.25	38.23	-16.85	2.09
Na	7.55	47.27	64.67	-39.72	1.37

(R: Rain water, Qf: Stream water from forested area, Qg: Stream water from lawn area)

5. Estimates of evaporation and snowmelt by energy budget

5.1 FRAME OF ENERGY BUDGET NEAR THE LAND SURFACE

It has been clarified that HYCYMODEL was very effective converting and analyzing the observed hydrological data to the principal hydrological components in Section 4.3-4.5, but it became clear that some issues were as yet unresolved. This means that the application is still difficult for different climate regions because energy budget was not considered. Evaporation and snowmelt processes are usually discussed recently within the framework of energy budgets, because routinely observed meteorological data can be available for the hydrological research community.

Generally, the radiation budget is written as follows:

$$Rn(t)=Rs\downarrow+Rs\uparrow+Rl\downarrow+Rl\uparrow=(1-\alpha)Rs\downarrow+Rl\downarrow-\varepsilon\sigma T^4 \tag{27}$$

where, Rn is the net radiation, Rs↓ is the incoming short-wave radiation or solar radiation, Rs↑ is the outgoing short-wave radiation, Rl↓ is the incoming long-wave radiation or atmospheric radiation, Rl↑ is the outgoing long-wave-radiation, α is the albedo, ε is the emission ratio, σ is the Stefan-Boltzmann constant, and Ts is surface temperature. Rs↓ and Rl↓ can be observed by using equipment, and are possible to estimate by using formulas and substitute data such as sunshine ratio.

Net radiation is also written near the land surface as follows:

$$Rn=H+\lambda E+G+Ms \tag{28}$$

where H is the sensitive heat flux, λE is the latent heat flux, λ is the latent heat of evaporation, E is the evaporation, G is the soil heat flux, and Ms is heat used for snowmelt if it exists.

5.2 SVAT MODEL FOR THE ESTIMATES OF EVAPORATION AND SNOWMELT

In Equation (28), the rather applicable model is called the SVAT model (Soil- Vegetation-Atmosphere Transfer scheme). The Penman-Montheith model [20], [21] is a representative SVAT model developed on the basis of the Penman equation [22]. Penman [22] made a model scheme on the wet land surface, but Penman-Monteith [20], [21] expanded it to unsaturated land surfaces with vegetation cover. Furthermore, this framework was expanded considering the interactions among each component, aimed at the numerical simulation of land surface processes such as evaporation, snowfall and the change of active layer depth in Siberian permafrost regions [16]. This model, that may be sometimes called the big-leaf model or the single layer model, was applied to a mountainous headwater in Japan, aiming at the estimation of evaporation, snowfall and snowmelt [17].

The latent heat flux, λ E and the sensible heat flux, H are written as the following equations in the big leaf model.

$$\lambda E = \frac{\Delta(R_n - G) + \rho_a c_a \delta q / r_a}{\Delta + \gamma(1 + r_s / r_a)} \tag{29}$$

$$H = \frac{(R_n - G)\gamma(1 + r_s / r_a) - \rho_a c_a \delta q / r_a}{\Delta + \gamma(1 + r_s / r_a)} \tag{30}$$

where Δ is the slope of the saturated vapor pressure curve at air temperature Ta, γ is the psychometric constant, c_a is the specific heat of the air, ρ_a is the density of air, δq is the specific humidity deficit, r_a and r_s are aerodynamic resistance and surface resistance, respectively.

The aerodynamic resistance, r_a is written as follows:

$$r_a = \frac{1}{\kappa u_*}\left[\ln\left(\frac{z_w - d}{z_{oh}}\right) - \Psi_k\left(\frac{z_w - d}{L}\right)\right] \tag{31}$$

where z_w is the measurement height, d is the displacement height, z_{0h} is the roughness length for scalar variables, κ is Karman's constant, u_* is the friction velocity.

The friction velocity, u_* is written as follows:

$$u_* = \frac{\kappa u}{\left[\ln\left(\frac{z_w - d}{z_o}\right) - \Psi_m\left(\frac{z_w - d}{L}\right)\right]} \tag{32}$$

where u is the wind speed, z_0 is the roughness length for momentum. The terms of Ψ_h and Ψ_m in Equations (31) and (32) are the stability correction functions for scalar fluxes and for momentum, respectively.

If snow-surface exists on the land, the following equation is available.

$$Ms = \varepsilon(Ld\downarrow - \sigma Ts^4) - H - \lambda E + G \tag{33}$$

The surface temperature has the following relationship of air temperature, Ta and sensible heat flux, H

$$Ts=Ta+H\frac{\gamma_a}{\rho_a c_a} \quad \text{------------------------------} (34)$$

By Blyth and Harding [1], the surface resistance, r_s can be explained by the next equation,

$$Rs=r_{s\min}\exp(\beta\delta q) \quad \text{------------------------------} (35)$$

where r_{smin} is the minimum surface resistance and β is a constant.

Ma et al. [17] have found the value of r_{smin} has a linear relationship to the radiation-dryness index, RDI, which is determined by the net radiation divided by the precipitation during two or three months, shown in Figure 18.

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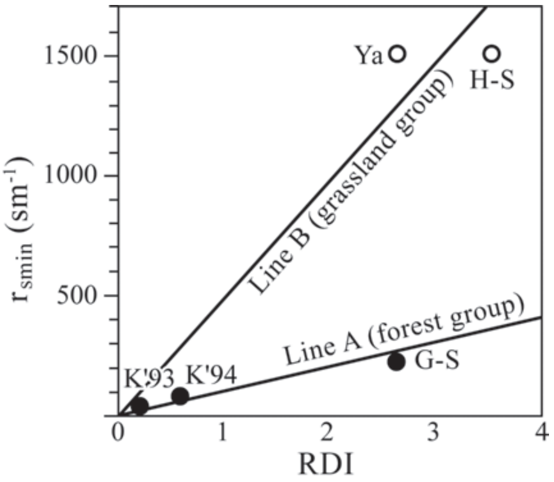

Figure 18. The relationship between Radiation-dryness index, RDI and Minimum surface resistance, r_{smin} (Ya: grassland in Yakutsk, Siberia, H-S: bush-land in HAPEX-Sahel, G-S: Forested area in Yakutsk, K'93: Ashu, Japan 1993, K'94: Ashu, Japan 1994), [17].

With the development of the SVAT model, it has become possible to estimate evaporation and snowmelt amounts quantitatively for forest and grassland, in different climate regions. Nowadays, this SVAT model is replacing the evapotranspiration components of the previously proposed HYCY model. The estimation of snow melt is shown as Figure 15. It shows an example of a forested mountainous basin in rather warm-temperate climate conditions.

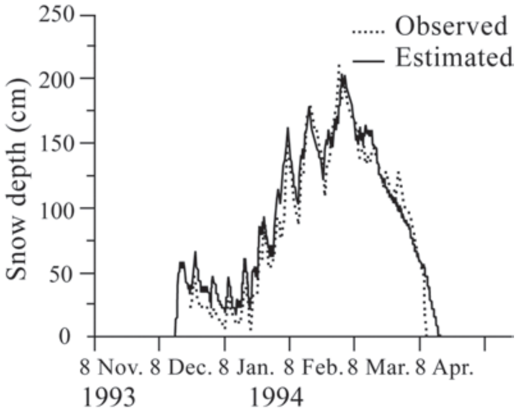

Figure 19. An change of snow depth estimated by the SVAT model in the Ashu Experimental Forest 0f Kyoto University, Japan [17].

6. Hydrology of headwater wetlands

The reasons for the existence of a headwater wetland seems firstly to be that it has either many rainy days or little evaporation amount, secondly that the slope system can supply comparatively much of the lateral flow because of the rich base flow component, and thirdly that the capacity to outflow to downstream is topographically limited. In a sense, headwater wetlands are formatted by the conditions of climate, geology and topography.

In Japan, headwater wetlands are seen in mountain areas with high altitude and are conserved as valuable spots of lovable landscape with special types of fauna and flora. On the other hand, wetlands in areas of low altitude are apt to be developed into agricultural areas by reclamation and drainage works.

Generally, headwater wetlands may be different in water quality from those in rather dry areas, and these have thick deposits of organic matter because decomposition is so delayed. At the same time, it must be remembered that most headwater wetlands are sensitive to climate change and are in unstable geomorphological conditions.

7. Acknowledgement

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ROLE OF GRASSLAND ECOSYSTEMS IN PROTECTION OF FORESTED WETLANDS

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KEYWORDS / ABSTRACT: Acid atmospheric deposition / forested wetlands / herbaceous vegetation / run-off genesis / surface water chemistry / recovery

The *Protected Headwater Area of the Jizera Mountains* was proclaimed in 1978 to support the important role of local headwater catchments in water and soil conservation. However, an ecologically oriented watershed management had not been realised until 1990s. In the 1970-1980s, watersheds of the Jizera Mts. declined as a consequence of the acid atmospheric deposition (namely sulphate originate by lignite combustion), and commercial forestry practices (spruce plantations of a low stability, extensive clear-cut, heavy forest mechanisation, non-effective control of insect epidemics, and unsuccessful reforestation). Both run-off genesis and water quality in streams and reservoirs deteriorated. Particularly, the erosion of soil increased from 0.01 to 1,34 mm/year, and sediment run-off up to 30% of the soil volume eroded. In the surface waters, low pH values (4-5), high content of toxic metals (namely aluminium, 1-2 mg/l), extinction of fish and drastically reduced zooplankton, phytoplankton and benthic fauna were observed. A recent recovery of surface waters in the Jizera Mts. (an increase in mean annual pH values to 5-6, a drop in aluminium concentrations to 0.2-0.5 mg/l, successful reintroduction of brook char, *Salvelinus fontinalis*) results namely from the decreased air pollution (in the 1990s, the deposition of sulphate decreased to cca 40% in comparison with the year 1987), and from the stabilisation of forested wetlands by grass cover (at clear-cut areas, the leaf area index dropped from 18 to 3.5). After the clear-cut of spruce plantations, Junco effusi-Calamagrostis villosae became a new dominant community in headwater catchments of the Jizera Mts. During the period of 13 years, at the clear-cut slope of the Jizerka catchment, the composition of herb layer changed following increased moisture conditions. The Ellenberg's soil mosture index increased in each point of the investigated slope. Headwater pet-lands play an important role in fixing the free Al^{3+} in organic complexes not toxic for fish.

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 49–58.

1. Introduction

Mountain forested wetlands are valuable and fragile components of a watershed [8]. Mountain bogs and fens provide watersheds with a large scale of downstream benefits. Traditionally, it is widely considered that they serve important ecological functions in supporting biodiversity and preventing downstream flooding by absorbing precipitation. Recently, bogs have been recognized for their role in regulating the global climate by storing large amounts of carbon in peat deposits [12].

In the Jizera Mountains (350 km^2, altitude of 50^{o}40' - 50^{o}52', longitude of 15^{o}08' - 15^{o}24', humid temperate zone, Northern Bohemia, Czech Republic), peat soils and peat bogs are important parts of forested headwater catchments. In the 1980s, headwaters of the Jizera Mts. have been declined as a consequence of the acid atmospheric deposition, die-back of spruce plantations, and commercial forest practices (an extensive clear-cut and use of heavy mechanisation). Strategies of nature protection and conservation (Landscape Protected Areas, Nature Reserves or Protected Headwater Regions) were not effective because of a very limited focus [6]. Reforestation of large cleared areas was complicated and the upper plain of the mountains has been overgrown by invasive grasses (particularly *Calamagrostis villosa*).

Figure 1. Headwater bog fed from upslope sources in the Jizera Mts.

The aim of this research was to evaluate the role of grassland ecosystems on hydrological processes feeding headwater wetlands, as well as on their downstream benefits.

2. Methods

In 1982, the small headwater basin Jizerka (area of 100 ha, elevation: 860-980 m) was instrumented. The long-term hydrological investigation has been conducted to study effects of clear-cut of mature spruce stands and succession of herbaceous communities on water phenomena.

Gross precipitation was measured in the open field, through-fall was observed on two plots (30x30 m, 900 m^2) installed under the canopy of a mature spruce stand and under the herbaceous vegetation. Both plots were instrumented with 10 rain-gauges.

Since the time of clear-cut, botanical data were collected in vegetation seasons. Phytosociological relevés (4 x 4 m, Braun-Blanquet scale) were taken at each 100 m of the main slope of the basin. To include the impact of all species abundance, the data were transformed from the Braun-Blanquet scale to a nine-point scale according to [7]. For each relevés, the indication value of soil moisture was evaluated as a weighted average of particular indication value of all species present [2].

3. Results

3.1. ACID ATMOSPHERIC DEPOSITION

At Jizerka, the acid atmospheric load measured in the open field culminated in the late 1980s. Sulphate was 45% and nitrate 16% of the total atmospheric deposition. In the early 1990s, the acid atmospheric load of the open field already dropped to 40% of the 1987 level. This corresponds with the decreased SO_2 concentration in the air (Figure 2), resulting from the reduced productivity of coal power stations in central Europe, namely in former East Germany.

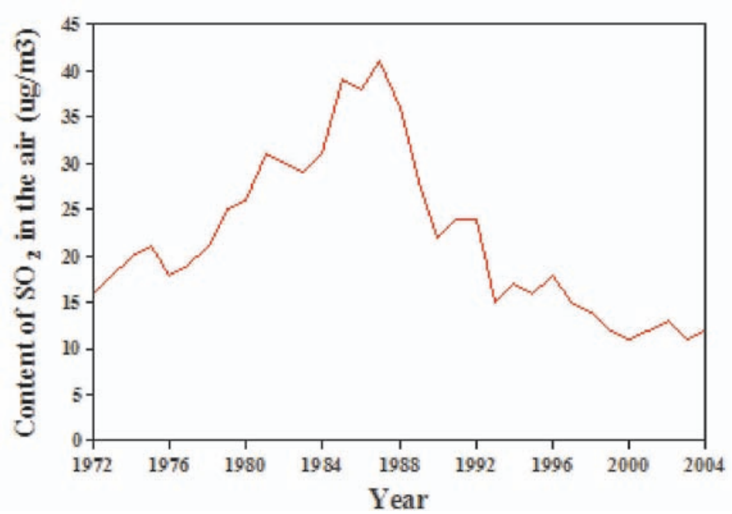

Figure 2. Mean annual content of SO_2 in the air: the Jizerka station (860 m a.s.l.), 1972-2004.

However, the atmospheric load of sulphur observed under the vegetation is still much higher than in the open, especially in spruce stands where the deposition decreases with defoliation. Much lower deposition of sulphur was measured under the herbaceous vegetation in cleared stands (Table 1).

	Spruce stand	**Spruce stand**	**Grass**
Defoliation (%)	35	75	-
Gross precipitation (mm)	1254	1254	1254
Throughfall (mm)	878	994	1056
Interception (mm)	376	260	198
Precipitation pH	4.4	4.4	4.4
Throughfall pH	3.8	4.1	4.5
Open field sulphur deposition (kg/ha)	11.8	11.8	11.8
Canopy sulphur deposition (kg/ha)	34.5	28.7	12.4

Table 1. Annual deposition of sulphur in mature spruce stands and herbaceous vegetation: Jizerka (980 m a.s.l.), 2000-2004.

3.2. SUCCESSION OF THE HERBACEOUS VEGETATION

After the clear-cut of spruce plantations, Junco effusi - Calamagrostis villosae became a new dominant community in headwater catchments of the Jizera Mts. However, during the period of 13 years, at the clear-cut slope of the Jizerka catchment, the composition of herb layer changed following increased moisture conditions. The Ellenberg's soil mosture index [2] increased in each point of the slope investigated (Figure 3).

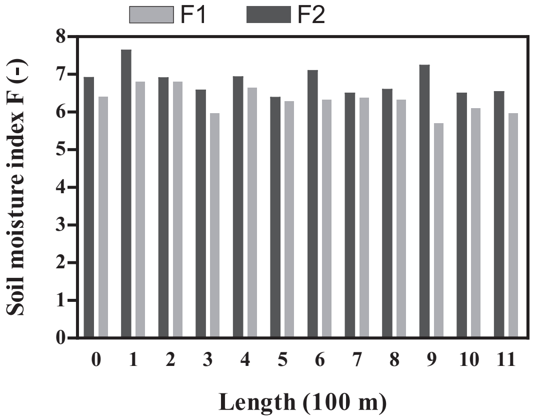

Figure 3. The soil moisture index at the investigated slope (1,100 m) of the Jizerka catchment (860 - 980 m a.s.l.): 1991-92 (F1) and 2002-03 (F2).

With higher moisture status, the effect of slope gradient on soil moisture is less evident (Figure 4).

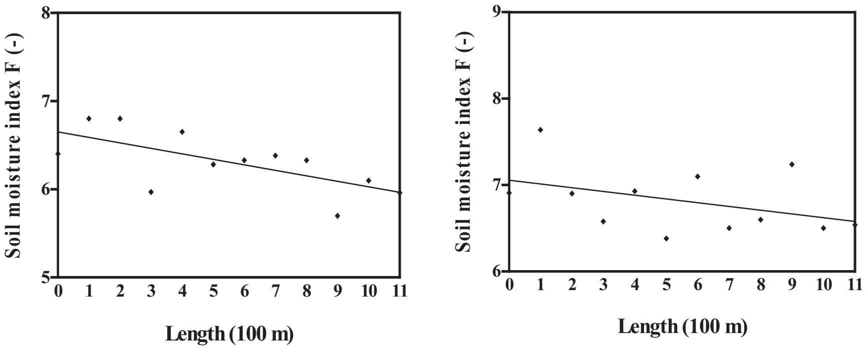

Figure 4. The soil moisture index decreasing with the slope length from the basin outlet of Jizerka (860 m): 1991-92 (left) and 2002-03 (right).

After the clear-cut, depleting the moisture storage of the catchment is not so intensive in comparison with the mature spruce stands. This corresponds to lower evapotranspiration and higher water yield (+108 mm) measured at the outlet of the catchment.

The herb vegetation plays a very important role in the protection of exposed cleared slopes to surface run-off and soil erosion. Although the infiltration capacity of the soil at investigated plots decreased dramatically from 150 to 40 mm/h, the measured sheet erosion there was still negligible. The significant soil erosion was measured only in the rills originated by skidding of timber. Thus after the clear-cut, the erosion of soil in the Jizerka catchment increased from 0.01 to 1,34 mm/year, and sediment run-off up to 30% of the soil volume eroded.

3.3. DECLINE AND REGENERATION OF STREAM-WATER CHEMISTRY

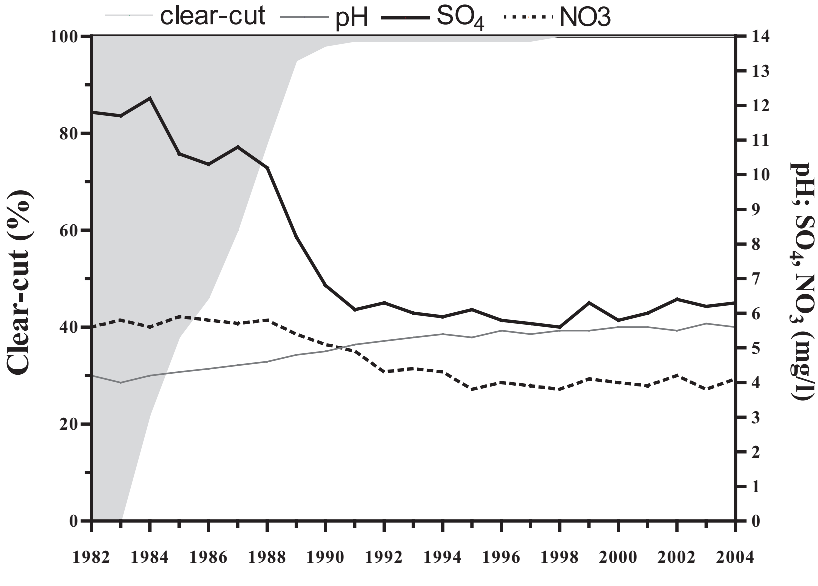

Figure 5. Stream-water chemistry and clear-cut of mature spruce stands: the Jizerka experimental basin, 1982-2004.

In the 1970-1980s, the water quality in water courses and reservoirs of the Jizera Mts. declined significantly: pH values dropped to 4-5, the content of aluminium increased to 1-2 mg/l (with a high level of toxic forms of aluminium - free Al^{3+} as well as inorganic complexes of Al), benthic fauna was reduced. In three headwater reservoirs (Bedrichov, Sous and Josefuv Dul), the extinction of fish was documented, and both zooplankton and phytoplankton were drastically reduced [10]. Seasonal changes in the water chemistry (episodical acidification after snowmelt or rain-storm) are relatively high.

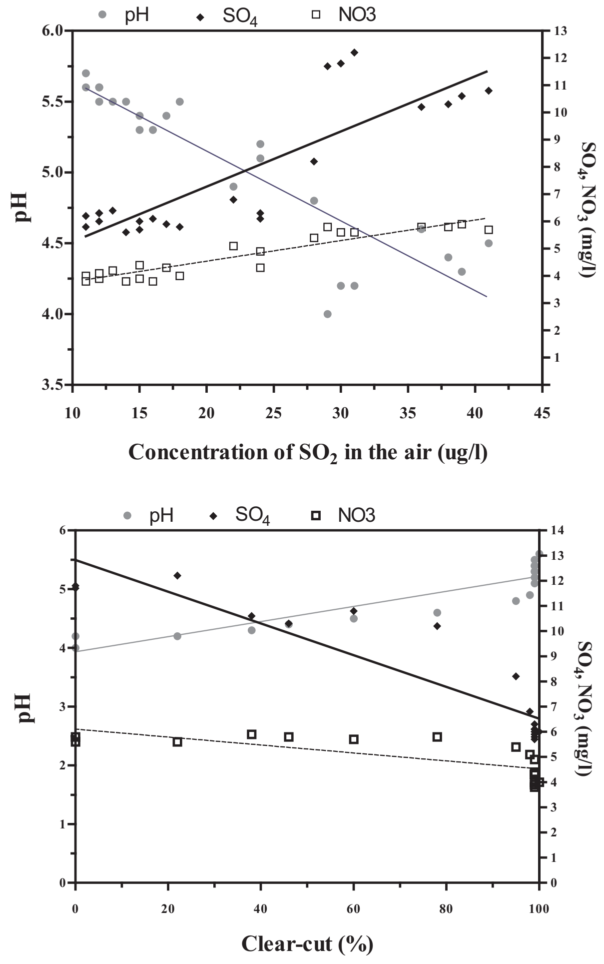

Figure 6. The effects of drop in SO$_2$ emissions and clear-cut on stream-water chemistry (Jizerka catchment): regression analysis (compatring the effect of clear-cut on the drop of sulphate $r^2_{0.05}$ = 0.86; for the effect of reduced SO$_2$ emissions on the drop of sulphate $r^2_{0.05}$ = 0.72).

In surface waters, the first signs of a recovery were observed already in the early 1990s as a consequence of reduction in the leaf area (and the atmospheric deposition under the canopy) of spruce plantations.

After the clear-cut of spruce stands, significant changes in stream-water chemistry of the Jizerka catchment were found (Figure 5 and Figure 6): mean annual values of pH increased from 4.0 to 5.3, concentration of sulphate decreased (from 13.0 to 6.0 mg/l) as well as nitrate (from 6.0 to 4.0 mg/l).

3.4. REINTRODUCTION OF FISH

Since the 1950s, surface waters of the upper plain of the Jizera Mts. were fishless as a result of the extremely acidified environment and the related high content of toxic metals. Ideas of a possible fish reintroduction were initiated by an improvement in physical and chemical parameters of the waters observed in the early 1990s (Table 4).

Pollutants	**Content** (mg/kg) **muscles**	 **liver**	**Hygienic limit** (mg/kg)
Mercury	0.04 - 2.6	0.05 - 6.2	0.01
Cadmium	0.1 - 0.4	0.4 - 6.2	0.05
Lead	1.4 - 2.7	1.3 - 7.0	1.0
Aluminium	6.6 -18.2	13.1 –90.7	30.0

Table 2. Pollutants in brook char of the Bedrichov and Sous reservoirs, 1996-2000.

In 1991, brook char (= brook trout, *Salvelinus fontinalis*, the most acid-tolerant species) and brown trout (*Salmo trutta* morpha *fario*) were experimentally reintroduced to the inlets of the Bedrichov reservoir. The char could survive and reproduce: a sufficient amount of food and well proportioned age structure and individual growth in the population were observed in the following years. The individuals of brown trout evidently starved and did not reproduce. In 1996, the Sous reservoir and its inflows were stocked with 30,000 fingerlings of brook char; this population also survives successfully. However, the concentration of aluminium and heavy metals in the fish still exceeds the hygienic standard (Table 2). The high content of Al and heavy metals in fish tissues originates from the dominant component of food - benthic Ephemeroptera (mayflies) and Trichoptera (caddisflies, *Hydropsyche* sp. dominating) in which extremely high values were found: 150-218 mg/kg of aluminium, 0.1-0.5 mg/kg of mercury, 0.3-4.0 mg/kg of cadmium, and 1-54 mg/kg of lead.

The survival of fish in surface waters of the upper plain of the Jizera Mts. seems to be limited by episodic drops in pH values and the level of toxic forms of aluminium (free as well as inorganic complexes of Al). For a rapid mobilisation of the toxic aluminium from the soil, the limit of pH seems to be 5.3. According to the survival of fish, the critical value of the toxic aluminium 300 µg/l is considered. In surface waters, both limits are still exceeded during the snowmelt and rain-storms. Headwater pet-lands play an important role in fixing the free Al^{3+} in organic complexes not toxic for fish [6].

4. Conclusion

The contemporary improvement of surface water quality in the Jizera Muntains is a consequence of both the decrease in air pollution and the reduction of leaf area (and, roughness of the canopy) by the clear-cut of spruce stands. The natural succession of the herb layer play an important role in the stabilisation of slopes, and controlling run-off genesis and water quality, as well as the environment of forested wetlands.

5. Acknowledgements

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THE EFFECT OF PEAT LAND DRAINAGE AND AFFORESTATION ON RUNOFF DYNAMICS:

Consequences on Floods in the Glomma River

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KEYWORDS / ABSTRACT: Peat land / drainage / forestation / runoff dynamics

Drainage of peat land results in drier soil cover and reduced evaporation. This, in turn, generates higher annual runoff. However, the main hydrological effect of mire drainage is related to changes in the pathways of water through the soil, not to the change in water balance. Mire drainage can contribute both to increase and reduce runoff peaks. Changes in runoff can occur both as a direct and an indirect effect. The direct effect depends on peat hydraulic properties, mire type, the hydrological situation and drainage intensity. Where the afforestation is successful a denser forest cover will indirectly lead to reduced storm runoff as evapotranspiration will increase. The snowmelt runoff will also fall due to decreased snow melting rates and less snow accumulation. Where the peat has low hydraulic conductivity, which is often the case with fens, the drainage will result in a relatively high ground water table, low water storage capacity and rapid runoff. On mires with a high fibre content, low density and degree of humification, the conductivity and storage capacity can be relatively higher and drainage will result in increased water storage and reduced flood peaks. As time passes after drainage, the peat hydraulic properties will become saturated due to compaction by subsidence and increased decomposition, which in turn causes the runoff to increase again.

The impacts of ditching depend on the type of mire in question. On fens with a supply of water from upland fields, ditching may increase runoff from the whole watershed by bypassing the runoff from an upland area faster than the fen would have done in its natural state. Ditching of bogs causes changes in runoff dynamics only from the peat land itself. During small rainfall events on unsaturated mires, a major part of rainfall is stored and the runoff is delayed. With heavy rainfall on saturated peat, drainage here can lead to faster runoff. Runoff peaks from snowmelt are higher on drained areas if the outlet before ditching was unable to carry the melted water and if the ditches are not blocked with snow and ice. Forest stands have a dampening effect on snowmelt runoff. The snow accumulation may be reduced by 30 % in forest stands compared to clearings. Snowmelt in dense forest stands is about 2 mm/degree day. In clearings, the snowmelt is in the range 3

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to 6 mm/degree day, mainly due to increased albedo. In the Glomma watershed, drainage of forest area has probably not contributed to higher runoff rates and increased flood peaks, as only a smaller portion of the watershed has been drained and because the forest growth has increased due to the drainage effect. In smaller watersheds with a high proportion of drained peat lands, especially fens, the flood peaks are likely to have increased.

1. Introduction

HYDRA was a research programme on floods initiated by the Norwegian Water Resources and Energy Directorate (NVE) The programme was initiated after a large flood in the south-eastern part of Norway in 1995 in the watersheds of the rivers Glomma and Gudbrandsdals- lågen. The flood was created by rapid snowmelt in a high altitude area combined with a 50-70 mm rainfall in the lowlands. During the flood several villages and more than 14000 ha of agricultural land were inundated, resulting in considerable damage. The extraordinary magnitude of the flood, both in volume and peak level, triggered a discussion of whether the severity of the flood was caused in part by man-made changes in land use. The working hypothesis was that the sum of all human impacts as relates to land use, hydropower development, river regulation, flood embankments works, etc., may indeed have increased the risk of floods.

The main objective of the HYDRA project was to support knowledge on effects of watershed management practices on floods, and to develop methods to reduce flood risk. The effect of drainage of peat land was considered to have contributed considerably to the flood peak in 1995. In many Norwegian watersheds, large areas of peat land have been drained for agricultural production and forestry. Therefore, drainage might have had some effects on run-off patterns.

The aim of this study is to evaluate the effect of peat land drainage on flood peaks. Existing literature on the effect of drainage is reviewed. Some calculations are presented on the effects of drains and soil moisture storage on runoff generation. Finally, a conclusion is made on the effects of drainage based on the information on the area drained and on the results of this review.

2. Peat land drainage in Norway

Drainage has been carried out to improve the growing conditions for peat land. Ditching increases temperature, content of oxygen and biological activity. In Norway, cultivation of peat lands began in the 17th century. Drainage continued on a large scale with government support until the 1970s when subsidies were discontinued and drainage reduced. Altogether about 200,000 ha have been drained for agriculture, 400,000 ha for forestry, and approximately 27,000 ha for peat production. In some regions such as in Sørlandet, the southernmost part of Norway, peat land today occupy as much as 25 % of the agricultural land.

In forest stands the open ditch network has been dug quite irregularly. Usually, the distance between the ditches has been 20-50 m. The agricultural drains have been more densely placed at 0.8 m depth and with 7-8 m intervals. The forestry drains have not been maintained to the same extent as the agricultural drains. In total, the proportion of drained area is only 20 % of the peat land area, making up about 3 million ha, which is considerably less than in the other Nordic countries.

Region	**Forest area (ha)**	**Drained area (ha)**			
	1997	**1920**	**1950**	**1980**	**1997**
Østfold	936,000	1,234	48,902	117,828	131,123
Hedmark	11,593,000	21,123	352,820	803,190	892,064
Oppland	5465000	4,778	128,874	279,118	293,322
		Drained area (% of forest area)			
Østfold	936,000	0.1	5.2	12.6	14.0
Hedmark	11,593,000	0.2	3.0	6.9	7.7
Oppland	5465000	0.1	2.4	5.1	5.4

Table1. The total mire area drained for forestry in southeast Norway in 1920-1997.

In the flood sensitive watersheds of Glomma and Gudbransdalslågen, the main reason for drainage of mires is to increase forest production. Drainage of forest land was particularly intensive in the 1950s and 1960s, when 5,000 ha was drained annually. In the period 1960 – 1985, 8-9 % of the forest area of Østfold County and 3-4 % of the forest area of Hedmark and Oppland Counties was drained. The affected area is larger than the 892,064 ha ditched, because ditching of fens might affect hydrology of the area surrounding a fen.

The statistics for forest and agricultural drainage in the regions covering the flood sensitive watersheds is given in Table 1. The percentage drained compared to the total forested area is largest in Østfold County. In most districts drainage has decreased steadily from the late 1960s. Today, mire drainage is generally not allowed and only a small portion is drained for agriculture, peat production, sport facilities and other kinds of urban development.

3. Introduction to Hydrological Characteristics of Peat and Peat land

3.1. DEFINITIONS AND CHARACTERISTICS OF NORWEGIAN PEAT LAND

Peat land is one type of a larger group of wetlands. Marshes, coastal flood plains and swamps have a mineral substrate and do not accumulate peat, whereas peat lands form in moist areas where the rate of production of organic material exceeds the rate of degradation which in turn results in organic peat deposits. Mires are usually used as a synonym for peat lands which are made up of a layer of peat exceeding 30-40 cm. Mires are classified based on hydrological characteristics as fens, which receive water from rainfall and from the surrounding area, or as bogs, where the rainfall is the only source of water input.

In Fenno-Scandia mires formed after the last Ice Age l0,000 years ago and reached their present appearance about 1000 BC. They were formed directly on mineral soils, from wet forests or from filling of lakes. Due to the varying climatic conditions in different parts of Norway, there is an exceptionally large variety of mires. Along the west coast, extensive rainfall results in very wet conditions, which sustain the development of peat on relatively steep slopes and the formation of blanket bogs which are not present elsewhere in Fenno-Scandia. The most common type of mire is fen (Aapa mires), which is found throughout the country. In the North, the ice formation and melting of these fens has resulted in large hummocks and in mires called Palsa mires. In parts of Norway with milder climate, the fens have grown, resulting in ombotrophy and the formation of raised bogs. Bogs are most abundant in the south-eastern part of Norway and in the Trøndelag region. Direct age measurements have not been made in Norway, but growth rate has been estimated at 0.2-0.4 mm/year [18]. Based on Finnish estimates the mires have grown to 60-70 % of their maximum size, which might be used as an estimate for the size of the Norwegian mires. The average depth of catotelm being observed in mire inventories is 2 m.

3.2 HYDRAULIC PROPERTIES OF PEAT

Mires consist of two different layers of organic material. The living and rapidly decaying plant layer (acrotelm) overlies a compact brown layer of partly decomposed peat (catotelm). The transition from one layer to the other is rapid. The depth of acrotelm is usually around 0.3-0.5 m. The soil properties governing flow are very different in these two types of layers. The hydraulic conductivity of the upper layer is about 0.1 m/s [7], [16]. The underlying layer has a considerably lower conductivity. The hydraulic conductivity increases with increasing fibre content and decreases with increasing humification and density [4]. The unsaturated hydraulic conductivity decreases rapidly with moisture content. This decrease is less for peat with an even pore size distribution. Well humified fen peat might have a higher unsaturated conductivity than bog peat [12]. The specific storage (S) of the upper layer is 0.8-1.0 and for the lower layer 0.13-0.26 [19], but these values are not well documented. A large variation in the peat properties is due to plant composition, degree of humification, stratification of the peat and compaction. A consistent difference between the hydraulic conductivities in the horizontal and vertical directions has not been observed [13].

Some properties of peat change following drainage [14]. Subsidence is a well-documented phenomenon. The primary subsidence of peat is caused by loss due to compaction of pores as the water table is lowered. Peat might be further compressed after drainage by wheel traffic from forestry and agricultural machines [14], which might be particularly high in case of low peat shear strength [19]. The secondary subsidence is caused by loss of carbon as CH4 and CO2, and due to leaching of carbon in runoff waters. An annual settling rate of 1.2-4 cm/year has been observed in Norway on cultivated peat soils.

3.3 HYDROLOGICAL FEATURES OF BOREAL PEAT LANDS

Some general conclusions can be made about the hydrology of pristine mires. Mires form in regions where the annual evapotranspiration (ET) is lower than the precipitation (P). The soils are relatively wet during periods when P exceeds ET because subsurface lateral and vertical water movement rates are variously limited by combinations of flat or low-lying terrain and low soil conductivity [14]. Poorly drained wetland soils are usually saturated near the surface during winter and early spring. The low gradient and near-saturated state make it likely that extensive saturation-excess overland flow will be produced [7]. Due to very little storage for rainwater, stream flow from peat bogs is poorly regulated. The old popular idea that mires act as sponges mopping up heavy rain is far from the truth if not entirely mythical [8]. The first rain after a long dry period may be effectively absorbed, but once the acrotelm is recharged the ability to retain further water is greatly limited.

Storm runoff response is controlled by the layering of the peat into two hydrologically different layers. It has been shown in many studies that runoff from mires depends on ground water level in the peat [13]. In response to rainfall, the water table may rise until it intersects the surface and the much higher permeability, and allows rapid runoff. If the ground water table lies in the transition between acrotelm and catotelm, as often is the case, rainfall results in rapid runoff response due to the very high conductivity of the uppermost layer. Due to low seepage rates from the catotelm, the base flow production from peat-covered catchments is very poor [7]. It has been observed that during dry periods in summer and winter the runoff might cease completely [3], [7], [15], [32]. The outflow from types of mires formed in valley depression, such as some fens, occurs in much the same way as for a lake i.e. controlled by the outlet configuration and the water level in the peat land. High runoff peaks during wet conditions and no flow during dry summer conditions are typical of these wetlands. It follows from the discussion above that virgin mires are characterised by a small portion of base flow and a rapid runoff response to rainfall.

Most hydrological studies of mires have been done on raised bogs where it has been shown that runoff depends on the interrelationship of ET and rainfall [14]. During the summer there may be periods of several days without rain, during which the water table falls from day to day. The plant roots extract water from both saturated and unsaturated zones and water is re-distributed at night to restore equilibrium above the water table [13]. Observations in the UK [13] show that the transpiration compared to potential evapotranspiration is very low in the early part of the summer but picks up in late June and peaks in July found that transpiration was between 50-60% of the potential evapotranspiration during the summer months and postulated that the ratio would rise to 80 % in September and remain at 100 % over the winter, as interception losses and evapotranspiration take over from transpiration. Total runoff is usually low with relatively low peaks during the growing season when ET maintains high soil moisture storage. During the dormant season when ET is low and soils remain saturated, heavy rainfall results in high peaks [14].

It should be noted that the hydrology of mires is site specific as it is depends on factors such as the surface inclination and the geological setting where the peat land has been formed. Due to the influence from the upland area, the hydrological characteristics of fens are site specific and not as well known as those of bogs, which receive water input from rain alone. In the event of a large surrounding catchment draining to a fen, it is reasonable to assume that the base flow is sustained throughout the summer and the runoff is even higher than that from bogs [14]. On the other hand, if the surrounding up1and portion is small, the base flow might cease during summer as the water from the upland will have 'evapotranspirated' in the wetland. It has been suggested that the evaporation from fens is greater than from bogs, which results in a smaller annual runoff from fens [27].

4. Review of hydrological consequences of peat land

4.1 WATER BALANCE ON DRAINED AND UN-DRAINED MIRES

Several authors report an increase in low flows following drainage [15], [31], [32]. This is due to the decrease in evapotranspiration rates due to drier topsoil caused by the lowering of the water table after drainage. In natural conditions, evaporation has been found in some studies to be higher for fens than for bogs [17]. Eyzennan`s results [12] indicate that the soil cover will be drier for fens than for bogs after drainage and therefore the decrease in evaporation might be higher for bogs.

For drained bogs the general decrease in ET is almost 100 % in midsummer and is naturally less with developed tree stands [32]. Perhaps the most important reason for the increase in base flow observed in many studies [32] is due to the fact that the soil water storage capacity is increased and the release of water from this storage maintains a high runoff throughout the summer. The increased discharge of artesian groundwater may in some cases increase summer and winter low-water runoff. An estimate of summer low-water increase is given as 50% by Sirin et al. [32] depending on the level of alteration in the drainage area.

Most research points out that drainage does not have a significant effect on the annual runoff coefficient. The annual water balance from mires tends to be similar to the overall regional water balance. Sallantaus [30] found that the annual runoff from Finnish peat mires is equivalent to the annual runoff in Finland, which means that on average 46 % of the 660 mm of rainfall runs off. The proportion of rain that generated runoff during previously reported annual runoff coefficients from drained areas was: 47 [6], 50 [30] and 69 [26]. These coefficients are in the same range as values previously observed from un-drained areas: 16 [26], 36 [34], 50-62 [7], 60 [10], 73 [26], 79 [6] and 84 [30]. The variation in runoff-coefficients is partly due to problems in measuring the water balance from mires [7], [27]. The loss of precipitation through interception is difficult to quantify because of a rather variable vegetation cover and the density of near-ground vegetation [13]. Despite small changes to the water balance, drainage changes water pathways [7] and effects individual storm peaks [19].

4.2 CONSEQUENCES OF DRAINAGE ON PEAK FLOWS

Previous studies of the effect of drainage on peak flow have provided mixed results [7], [29]. In a majority of cases a decrease [7], [23], [15] in peak flows have been reported after drainage, but an increase in floods has also been noted [9], [20], [31], [26]. The divergent effects on flows are partly due to the fact that drainage has both reducing and increasing effects on peak flows. Soil water storage may increase temporarily due to drainage and thus store part of the rainfall, whereas the channel network and the higher hydraulic gradients result in a quicker runoff [32], [19]. When additional factors affecting runoff are included, such as interception, rainfall intensity and surface morphometry, the assessment of drainage impacts becomes even more complicated [32].

During the non-frost season the main factor determining the peak on drained areas is whether overland flow in the acrotelm will occur or not. If the infiltration and storage capacities are not exceeded, the rainfall will only result in a rise in the catotelm groundwater level and the runoff will be small compared to undrained cases, where the runoff usually occurs in the acrotelm [19]. If the groundwater level rises close to the surface on drained areas, the runoff will increase. On most drained forest areas the catotelm storage will quickly be filled up and result in rapid overland flow if rain continues to fall. In ditched forest areas, the moisture deficit in the peat was rapidly satisfied, and the runoff peak was not markedly reduced by increased infiltration, at least not for heavy rainfalls [19], [31], [32]. A fivefold increase in peak runoff was observed on a Russian mire after ditching [32]. An increase of 131 % in summer peak runoff and 31 % during snowmelt peak runoff was noted after drainage in Finland with 60 cm drain depth, 40 m spacing and 40 % drained area [31]. However, 10-20 years after forest growth the drainage impacts were reduced. The spring maximum peak was 13 % smaller on the ditched area. The summer maximum was only 19 % larger on a ditched than on an unditched mire. The decreasing peak flows were related to much lower flood peaks in that period, to increased interception in the forestry canopy and to impairment of the ditches. A reduction in spring runoff after drainage when the canopy had developed has been noted by Heikurainen et al. [15].

The effect of the location of the drained area within the river basin on peak flows and timing of the peak has got some attention in the literature. Sirin et al. [32] have observed that peak runoff increases most when the drained area is situated in the upper part of the watershed. Sirin et al. [32] also showed with modelling that an even distribution of the drained area results in the lowest peaks, and that the highest peaks are observed when the drained area is close to the outlet of the drainage area, which is often the case when fens are drained. Seuna [31] observed that the peak occurred 1.5 days earlier on drained areas compared to un-drained catchments, which was related to drainage itself and clear-cutting.

Very little attention has been paid to the effect of drainage on runoff from upland areas surrounding fen mires [5]. This is unfortunate as fens in particular are suitable for drainage and forestry due to the higher nutrient status. On wetlands the upland water is partly intercepted and evaporated. After drainage the upland water is conveyed in artificial channels. Therefore, drainage evidently increases runoff from the upland portion of catchments. The effect on the flood peak is probably small as the runoff from mires is also quite rapid due to the high conductivity.

The hydrology of boreal mires is dominated by impacts of snow pack and frozen soil, which results in low runoff in the winter and high runoff during the spring snowmelt [14]. It has been assumed that the impact of forest drainage on snowmelt runoff is more complex than on summer runoff [32], although there are very few published results on snowmelt runoff from mires. Results from modelling [32] and observations [33] indicate that the effect of drainage on snowmelt runoff is small and only minor alterations in snowmelt hydrographs have been observed after drainage. Seuna [31] noted a somewhat minor increase in spring time compared to summer flood peaks in a ten-year period after drainage.

4.3 THE EFFECT OF AFFORESTATION ON RUNOFF

Much of the research on the hydrological effects of drainage has not included the effects of forestry and tree development despite the fact that peat land drainage is usually done to increase forest production. The experimental methods used have not managed to separate the hydrological effects imposed by ditching and the effect of tree development [14]. It is well known that the vegetation cover has a strong influence on the water balance [14]and that forests have widely been claimed to reduce flooding downstream [29]. The presence of forest cover is associated with reduced annual water yield. This has been demonstrated repeatedly by comparisons of similar forested and non-forested catchments and by noting the effects of deforestation, reforestation and afforestation [22]. According to Anderson et al. [1], previous results show that afforestation of conifers increases water yield of the vegetation by 140-390 mm in climates with less than 1000 mm rainfall.

Developing tree stands decrease runoff by altering snowmelt conditions and increasing interception and evapotranspiration. The development of canopy increases the surface area from where water can evaporate more rapidly. Rainfall quantity, duration and intensity, as well as the state of the crop, all play a part in determining the amount of interception. Robinson et al. [29] observed a halving of the runoff coefficient when the tree plants had grown from 2 to 22 years. Seuna [31], too, observed a decreasing trend in runoff as trees developed. The effect of forest on peak runoff from rainfall will depend on the soil moisture content. On mires with little seepage, increased evapotranspiration will result in increased soil water storage and reduce peak flows. During wet soil conditions, when precipitation exceeds evapotranspiration, the effects of forest in retarding peak flows is minimal, as the canopy storage only takes up about 2 mm of precipitation [22].

Several studies show that forests reduce runoff peaks from snowmelt [25]. Observations show less accumulation of snow in forest than in clearings, which has been related, in most cases, to the evaporation of intercepted snow [24]or to wind redistribution of intercepted snow [35]. A maximum loss of 3.3 mm/24 h has been found from two winter measurements in Sweden [24]. Some resent results in Sweden and Norway show that the interception of snow and the consequent loss in water yield can be up to 30 %.

The snowmelting rates used in snowmelt calculations from forested areas is smaller than from open fields. Generally, 2 mm/degree day has been reported from forests. The melt rate from open fields is higher and more variable than from forests. In early melting the rate is about 3 mm/degree and increases towards 5-6 mm/degree in the late snowmelt, mainly due to decreasing albedo. This indicates that in the late snowmelt 40 mm less water will run off from forests during a day of l0 degree Celsius. Indeed, timber harvesting in areas with substantial snow cover has been seen to increase snowmelt runoff [24]. Because the snowmelt from forested areas is smaller in magnitude and volume than from clear fields, it is logical to assume that afforestation of wetlands will result in smaller peak flows and smaller runoff volumes following snowmelt when the tree stand has developed.

4.4 THE EFFECT OF DITCH DEGRADATION

Over time the ditch depth on mires is reduced due to erosion, siltation, peat subsidence, freezing-thawing and vegetation. The reduction in depth occurs most rapidly during the first few years after ditching. The deeper the ditches are dug, the more rapid is the loss in ditch depth due to peat subsidence. The growth of Sphagnum and Carex in the ditches may decrease the ditch depth by 25 % after 5 years. Eventually, without any maintenance of ditches, the hydrological situation will return to its natural state. Observations in northern Finland show a decrease in ditch depth from 70-80 cm to 30-40 cm in 30 years [21]. Information is not available on how this affects runoff.

5. Effect of drainage on runoff: analysis of governing factors

Previous studies on drained and un-drained areas show converging results on the effects of ditching on peak flows. This is due to the fact that drainage has both a decreasing effect on peak flow due to increased soil water storage, and an increasing effect due to the large channel network and higher hydraulic gradients [32], [14]. The increased soil moisture storage capacity allows part of the rain to be temporarily stored in the soil which decreases flood peaks. On the other hand, when the moisture storage is filled up, continued rain results in rapid runoff as the increased channel network allows rapid overland and groundwater flow, thus enhancing floods. It is therefore important to evaluate the possible moisture storage in the peat caused by drainage.

When assessing the hydrological system of drained mires, there are three conditions that have to be fulfilled before large peak flows can be produced during or after rainfalls. These are:

- Soil and canopy water storage filled up.
- Rapid runoff from strips to ditches.
- Efficient channels to convey the increased overland flow.

When the canopy water storage is filled up, excess water will be infiltrated into the peat. When the field capacity has been reached, excess precipitation results in an immediate increase in groundwater level. The immediate increase in ground water level can be derived from effective porosity and rainfall. An increase in groundwater depth results in an increase in runoff as the hydraulic gradient is increased. In most cases it is reasonable to assume that the drainage network is able to carry the excess water away rapidly. It is also reasonable to assume that condition 3 does not usually control runoff. Where the ditches lack maintenance, the carrying capacity may have been reduced due to a decrease in channel depth by peat subsidence and increased channel roughness due to vegetation, erosion and siltation. Conditions 1 and 2 are probably the most restrictive factors for rapid runoff generation. Next we will estimate the effect of conditions 1 and 2, calculate the moisture storage available after drainage, and estimate the effect of drains on peak flows.

5.1 THE EFFECT OF SOIL MOISTURE STORAGE IN ATTENUATING PEAK FLOWS

Drainage of peat lands lowers the groundwater levels and increases the depth of the unsaturated zone. This may have a significant effect on runoff as the increased moisture storage allows rainfall to be temporarily stored in the peat [14]. The soil water storage after drainage will be evaluated in this chapter.

The depth of the unsaturated zone after drainage is dependent on the hydraulic conductivity of the peat, drainage intensity and drain depth. Where evapotranspiration from acrotelm is less than the moisture transport from the saturated catotelm, the soil moisture stays close to field capacity. The maximum rate of moisture transport depends on the depth of the groundwater table. Eyzerman [12] has shown with the Darcy moisture transport equation that 50 cm and 70 cm ground water depths for high-moor and low-moor, respectively maintain a 3-4 mm/ day moisture transport, i.e., if ET is below 3-4 mm/d the soil stays at field capacity. This is in agreement with field observations [28], when he observed that when the distance to ground water level remains below 60 cm the soil moisture content follows the theoretical matrix suction corresponding to the distance of the ground water table. The general drainage norm in Norway has been that the depth to the groundwater surface should be 30 cm [6]. Usually forest ditches have been 50-80 cm deep at 15 - 30 m distance apart. On agricultural land a ditch depth of 80 cm at 7-8 m intervals has been used in south-eastern Norway. Based on the relatively shallow drainage it is reasonable to assume that in the case of forest drainage the peat stays at field capacity, at least for groundwater fed fens, receiving a constant seepage of water from the upland.

Some approximate calculations have been made on the capacity of the soil moisture storage after drainage when the peat is at field capacity. This is done based on observations by Paivanen [6] on moisture in forestry drained Finnish peat soils. The results of these calculations indicate that the initial soil moisture storage is usually filled up by rainfall below 10mm, indicating very little moisture storage on forestry drained mires. In most cases, severe floods in the non-frost season occur due to periods of large rainfall. On such occasions moisture storage does not have a large effect on floods. According to Sirin et al. [32] peat soil storage also has little effect due to the hydro-metrological conditions prevailing during flood periods. This agrees with studies in Finland on forestry drained peat lands, where it has been observed that soil moisture storage has an attenuating effect on small rainfall events only and not on large events (Seuna 1981). Open drainage is well known to have little effect in lowering the water table of the adjoining peat land (Boelter 1972 in [13]). However, in some very special situations where the drain intensity is very high, the drains are deep and the soils relatively permeable as e.g., on some cutover peat lands, the increased soil moisture storage will attenuate the peak runoff considerably as observed in studies by Kløve [19].

5.2 THE EFFECT OF DRAINS IN GENERATING PEAK FLOWS FROM MIRES

On natural mires the water table is lowered in the summer time after periods of drought and low flow. When the water table rises in acrotelm, increased storm flow is generated due to high conductivity. At high water levels the storage coefficient is rather close to unity, which means that very large storms only cause a small rise in groundwater levels. Due to the high conductivity of the acrotelm, the transmissivity of the catotelm need not be accounted for.

Forested mires are, in their hydraulic behaviour, either similar to natural non-forested mires or similar to heavily drained cultivated peat land, depending of whether the groundwater table lies in the acrotelm or in the catotelm. The water table is generally in the catotelm during low flows. If the ditches are deep enough, recharge will not fill up the catotelm storage, the groundwater will fluctuate in the catotelm of low hydraulic conductivity, and the runoff will be similar to the runoff from cultivated and heavily drained peat lands. If the ditches are shallow, which is usually the case, the recharge will eventually fill the catotelm storage, the groundwater will rise into the acrotelm and increased recharge will be generated in the acrotelm as in natural mires. Because of the dual property of the forestry drained areas, soil properties similar to natural as well as heavily drained conditions needs to be used in a runoff calculation.

Peak flows from the different scenarios have been calculated, showing that drainage can either reduce or increase peak runoff. The main factor controlling whether the runoff increases or decreases is the location of the groundwater table before recharge occurs. If the mires are drained only to shallow depth, as is usually the case with forested mires, runoff will be generated within the acrotelm and drainage will increase the runoff peaks by almost one order of magnitude, from a peak runoff being about 10% of the daily rain intensity to a runoff peak corresponding almost to the daily mean rain intensity assuming that channel network is able to carry the storm water. The increase in peak flow is due to increased hydraulic gradients imposed by drainage. The results ([7], [18], [19]) show that runoff peaks from natural mires, about 7-20% of the daily mean rain intensity, tend to be larger than peaks from deeply plough-drained sites, the runoff peaks from the scenarios being about 7 % of the rainfall intensity. If the channels are deep enough, the groundwater table will fluctuate in the catotelm, where the hydraulic conductivity is low, so when the groundwater level controls the runoff, the peak discharge rates will always be smaller on deeply forestry drained areas than on natural mires. It should be noted that on some cultivated peat sites, the soil surface is lowered, compacted and the storage reduced. Here the groundwater level may reach the soil surface and initiate surface runoff which greatly increases peak flows.

6. Evaluation of the effects of plough drainage of peat land on flood peaks from Norwegian watersheds

Based on a review of the literature and theoretical calculations, it seems as if peat land drainage for forestry can both increase and reduce flood peaks. The effect obtained depends upon geological structure, geography, climate and ditching practices. The most important conclusions drawn from this study are:

- Ditching increases the un-saturated zone and therefore allows more rain to be temporarily stored. However, as this storage is rapidly filled, more runoff will be generated due to steeper gradients after drainage. This dual effect results in a reduction of small peak flows and an increase of intermediate peaks.

- Increased tree growth increases evaporation. Evaporation of intercepted snow results in less snow accumulation in forests than in clearings. The reduction in snow volume may be up to 30 %.
- The tree stands reduce snowmelt rates from 3-6 mm/degree-day to approximately 2 mm/ degree-day resulting in a smaller runoff peak after afforestation.
- Ditching of fens will probably increase the peak flow from the upland area. Most mires that have been drained in Norway are fens with a considerable portion of upland area. This implies that a considerably larger area than just the mires is affected by drainage. After ditching the runoff will increase if prior to ditching the runoff peak rates from upland were, at least partly, controlled by a poor carrying capacity of surface flow through the natural wetland. The importance of this effect is probably not significant as the hydraulic conductivity in acrotelm is large and the runoff also in a natural state flushy.
- The increase in intermediate peaks may result in changes of channel morphology so that channels become deeper, the flow resistance lower and the largest peaks become larger.

In the Glomma basin, the proportion of drained mires in large watersheds is generally less than 10 %. It is known that the drains function for not more than approximately 30 years. It is reasonable to conclude that the drained area is smaller than that given in table 1 and that the area of drained mires will be reduced in the future. Assuming a drained area returns to natural condition after 30 years, the drained area is well on its way to a natural state, as most of the drainage was carried out more than 30 years ago.

7. References

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IMPACT OF HERBACEOUS VEGETATION ON RECOVERY OF A HARVESTED HEADWATER CATCHMENT

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The processes of soil erosion and sedimentation may seriously affect mountain wetlands fed from surrounding upslope sources. In headwaters of the Jizera Mts., the potential annual loss of soil varies from 0.2 mm (mature spruce stands) to 1.2 mm (conversion to grass). Negligible sheet erosion has been observed at run-off plots covered by herbaceous layers. However, very important soil loss occurred in erosion rills originated by skidding of timber (from 0.3 to 1.2 mm/year). The critical parameter affecting the recovery of rills is their depth. The increasing depth of rills is related to a drop in both vegetation cover and number of species, and to a higher proportion of hemicryptophytes and plants forming clusters or bunches. These plants do not have a high potential to cover the soil surface, and to protect it against erosion. Thus, the process of soil erosion may be prolonged. The number of species (species richness) found in recovering rills increases significantly with the time (age of rills). From the point of view of soil protection, more shallow rills (depth from 0 to 0.25 m) can recover much better than only few deep rills (depth over 0.5 m). The shallow rills can re-grow quite fast, but in the deep rills, the spontaneous succession is very slow or even impossible. So, the rills deeper than 0.5 m require the application of reclamation techniques (stabilisation of the slope by check-dams etc.). It is evident, that environmental friendly forest practices may avoid the risk of soil erosion from the harvest of timber.

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Environmental Role of Wetlands in Headwaters, 77–86.

1. Introduction

The aim of this study was to evaluate impacts of spontaneous succession on erosion control in headwater catchments feeding wetlands (bogs or fens) in the Jizera Mts. (Czech Republic). In the 1980ies, headwater catchments in the Jizera Mts. were heavy affected by acid atmospheric deposition, dieback of spruce plantations (*Picea abies*), and commercial logging practices. The extensive clear-cut; and skidding of timber by wheeled tractors deteriorated the surface of wet forest soils, particularly in the upper plain of the mountains (Figure 1). At the clear-cut areas, heavy machinery directly deteriorated about 10 percent of the soil surface. The network of skid-roads and periodical drainage expanded from 1.3 to 4.7 km/km^2 [2].

Figure 1. Erosion rills after the clear-cut of spruce plantations: the Jizerka catchment.

After the clear-cut of spruce plantations, *Junco effusi-Calamagrostietum villosae* became the new dominant community in this region [6]. The leaf area index decreased from 18,0 (mature spruce stands) to a seasonal maximum of 2.7 (herb layers with the dominant invasive grass *Calamagrostis villosa*, plus reforestation). Thus, in the Jizerka experimental basin, the erosion of soil increased from original 0,01 mm/year (mature spruce plantations) to 1,34 mm/year (clear-cut). Consequently, the yield of sediment (sediment outflow from the catchment) reached almost 30 percent of the eroded soil [3]. In the

1990ies, the process of headwater rehabilitation started with the revival of traditional forestry (skidding the timber by horses or cables, respecting buffer zones, reclamation of erosion rills).

The spontaneous succession of herb vegetation in erosion rills was studied in relation to their depth, slope, length and age (time from their origin). The data were compared with herb vegetation found in clearings and dead stands of mature spruce.

2. Method

The inventory of erosion rills was carried out in the highest part of the Jizera Mts.: the Jizerka experimental basin (area of 1 km^2, elevation of 860-980 m), and the adjacent sub-basin of the Sous reservoir (5 km^2, 880-940 m) in 1982, 1985, 1988, 1992, 1995, 2002 and 2003.

The depth of rills was monitored in cross-sections marked at each 10 metres of their length. The volume of soil eroded was calculated from cross-sections and their representative lengths. The sheet erosion was observed at two runoff plots (30 x 30 m). Sediment yield from the Jizerka catchment was collected and measured at a gauging station (basin outlet).

Phytosociological relevés (4 x 4m, Braun-Blanquet scale) were taken to identify vegetation characteristics of erosion rills (plant cover percentage, species composition, life forms and growth types) [1]. The life forms of Raunkiaer [5], indicating differences in plant parts where the surviving tissues are located, are taken as:

- hemicryptophytes (Hkf, surviving buds or shoot apices situated near the soil surface);
- chamaephytes (Chf, surviving tissues borne on shoots slightly above the ground);
- geophytes (Gf, surviving buds or shoot apices buried in the soil);
- therophytes (Tf, plants that complete their life cycle from seed and die within a season); and
- phanerophytes (Pf, surviving buds or shoot apices borne on shoots which project into the air).

Within the growth types, plants forming above and/or underground tillers, and plants of simple stems or forming clusters/bunches were respected. The botanical data were analysed in groups related to categories of slope ($5/10^{o}$), depth (0.25/0.5 m) and age (0/4/6/8/10/15/20 years). Statistical analysis (ANOVA) was used to evaluate differences in vegetation features between particular stand groups.

3. Results

3.1. EROSION PATTERNS

The Universal Soil Loss Equation (USLE) [7] was applied to predict the soil erosion at the Jizerka experimental basin (instrumented since 1982): the rainfall factor R = 53 (annual precipitation of 1400 mm), the factor of soil erodibility $K_1 = 0.22$ (sandy loam with an original infiltration capacity of 150 mm/hour), $K_2 = 0.26$ (after reduced infiltration capacity to 40 mm/hour by the harvest of timber), the length factor L = 8.2 (length of the slope 1000 m), the slope factor S = 3.0 (slope of 18 percent), and the factor of vegetation and management $C_1 = 0.01$ (well stocked woodland managed), $C_2 = 0.05$ (grass). Thus the potential annual soil loss at the Jizerka basin is $G_1 = 2.9$ t/ha (0.2 mm) and $G_2 = 17.0$ t/ha (1.2 mm).

From field observations, negligible sheet erosion occurred in run-off plots of both forest (mature spruce stands) and clear-cut (invasive grass). However, the significant loss of soil was related to the length of erosion rills produced by the harvest of timber (Table 1).

Period	**1982**	**1982-85**	**1985-88**	**1988-92**	**1992-95**	**1995-02**
Soil loss (mm/year)	0.01	0.6	1.2	0.3	0.1	0.05
Length of rills (km/km^2)	1.3	2.4	3.9	4.7	4.7	4.7
Clear-cut area (%)	0	38	40	21	1	0
Clear-cut total (%)	0	38	78	99	100	100

Table 1. Soil erosion in the Jizerka catchment (1982 – 2003).

From an inventory of erosion rills, 14 were identified in the Jizerka catchment and 22 in the adjacent sub-basin of the Sous reservoir. The maximum depth of rills varies from 0.2 to 1.2 m related to their length and frequency of skidding. While the length evidently affects the depth of rills (Spearman $R_s = 0.88$, $R_{sc,\ 0.05} = 0.45$), the correlation between the depth and slope is not significant ($R_s = 0.24$, $R_{sc,\ 0.05} = 0.45$, Figure 2).

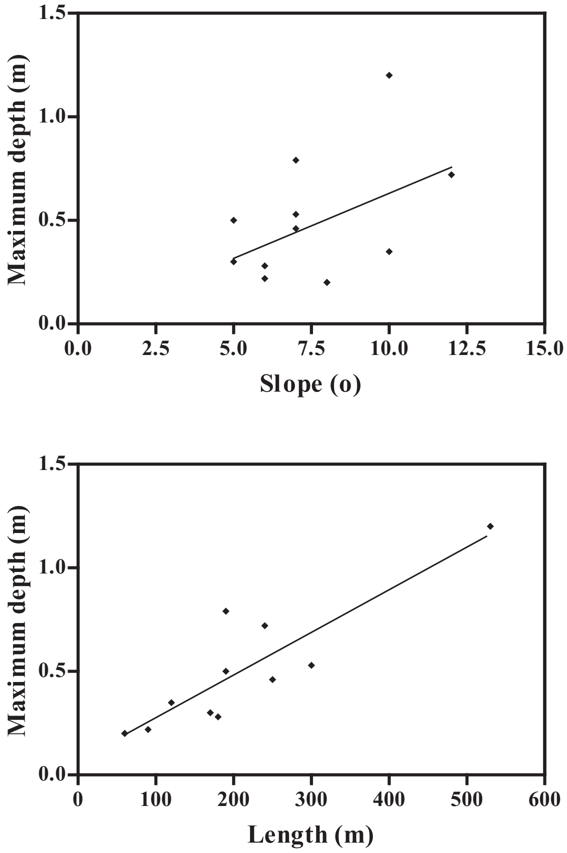

Figure 2. Erosion rills in the Jizerka catchment: maximum depth, slope and length.

3.2. HERB LAYERS AT STUDIED SITES

3.2.1. Shallow erosion rills

The plant cover varies from 25 to 98 percent, and species richness (number of species per relevé) from 4 to 10: mainly hemicryptophytes (*Agrostis stolonifera, Deschampsia caespitosa, D. flexuosa, Juncus effusus*; in older successional stages, *Calamagrostis villosa*) and phanerophytes.

3.2.2. Middle erosion rills

The plant cover varies from 20 to 75 percent, and species richness from 4 to 9: mainly hemicryptophytes (*Agrostis stolonifera, Deschampsia* *caespitosa, D. flexuosa, Juncus effusus, Calamagrostis villosa*). Plants forming clusters prevail, and seedlings of *Salix caprea* are frequent.

3.2.3. Deep erosion rills

The cover was found only in the range of 1 – 30 percent, and species richness 1 – 9: mainly hemicryptophytes (as listed above), but some plants of a shallow root system also found (*Sagina procumbens, Spergularia rubra*). The plants forming clusters represent on average 75 percent species present.

3.2.4. Dead forests

The cover of herb layer reaches 100 percent (as result of the high income of global sun radiation), and species richness is very low (maximum to 5). Only a few resistant hemicryptophytes (*Calamagrostis villosa, Deschampsia flexuosa*) are present.

3.2.5. Clearings

Plant cover percentage is 95 - 100, and species richness 5-10. Besides hemicryptophytes (*Calamagrostis villosa, Deschampsia flexuosa*, etc.), chamaephytes (*Vaccinium myrtillus, V. vitis-idaea, Galium harcynicum)*, geophytes (*Trientalis europaea* etc.), and young phanerophytes are also present.

3.3. DIFFERENCES BETWEEN SITE GROUPS

The observed erosion of the soil (Table 1) is characterised by the depth of rills related to their slope, length and skidding frequency. The loss of topsoil decreases both nutrient availability and soil seed bank at a particular site. Both these characteristics are highly important for the recovery of rills. Then, besides the seed rain, the succession depends on seed viability. Unfortunately, in the studied area, the flora (total number of plant species occurring) is rather poor. Moreover the seed germinability of species dominating in clear-cut areas - *Calamagrostis villosa* - is very low and rarely reaches 10 percent [4].

The difference in plant cover between studied site categories (1 – dead mature spruce stand; 2 – clearing; 3 – shallow rill: 0 – 0.25 m deep; 4 – middle rill: 0.25 - 0.5 m; and 5 – deep rill: deeper than 0.5 m) are shown in the Figure 3. Concerning the erosion rills, maximum values of both cover percentage and species richness were found in shallow rills, followed by middle, and then deep rills.

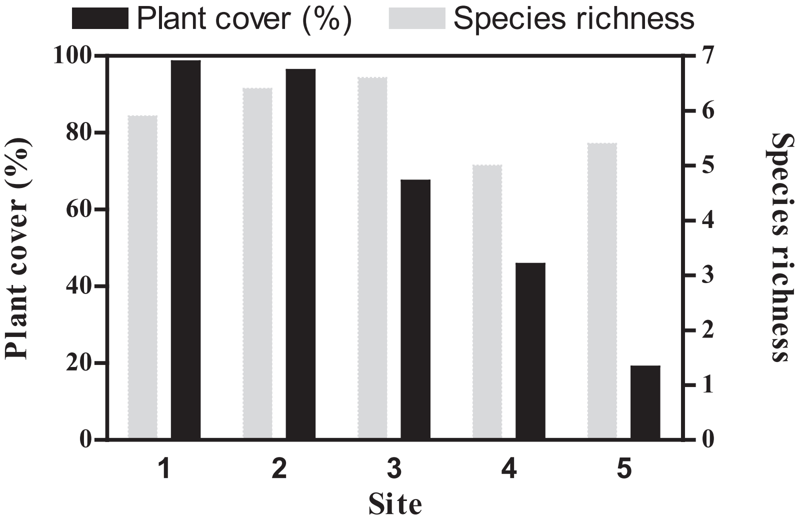

Figure 3. Species richness of studied sites (1 - dead forest, 2 - clearing, 3 - shallow rill, 4 - middle rill, 5 - deep rill).

	Cover (%)	**Species richness**	**Clusters (%)**	**Tillers (%)**	**Hkf (%)**	**Ff (%)**	**Chf (%)**	**Tf (%)**	**Gf (%)**
Rill age(yrs)	0,08	**0,54**	0,16	-0,07	**-0,31**	**0,28**	**0,46**	**-0,19**	0,07
Slope (o)	0,05	**0,21**	0,06	-0,00	-0,11	0,15	**0,22**	**-0,22**	0,08
Depth (m)	**-0,65**	-0,17	0,11	**-0,18**	-1,06	**-0**,05	0,11	-0,05	0,03
Cover (%)	1,00	**0,48**	- 0,09	**0,18**	-0,08	0,07	0,16	-0,02	0,06
Species richness	**0,48**	1,00	0,09	0,05	**-0,45**	**0,44**	**0,34**	0,05	0,17

Table 2. Correlation matrix of studied parameters (bold – significant R at p = 0,05).

The percentage of plant cover is related mainly to the depth of rills (R = -0,65) and the number of species (species richness) to their slope (R = 0.21, Table 2, Figure 3). Within the observed growth forms, a decreasing percentage of plants forming tillers was found with increasing depth of rills (from 35 percent in shallow rills to 28 percent in deep rills).

Concerning the life forms, hemicryptophytes (Hkf) are most common. They form almost 80 percent of life forms occurring in erosion rills and dead spruce stands, while only 60 percent in clearings. Young trees (Ff) and chamaephytes (Chf) occurred only occasionally, and therophytes (Tf, small annuals) were found only in erosion rills (i.e. sites where the damaged plant cover supports their accession).

3.4. EFFECTS OF THE AGE OF RILLS

At a particular stand, the age of a rill is registered by the year of logging. Although tractors can also occasionally re-enter existing truck- and skid-roads later too, the main skidding occurs just in the year of logging. Thus, the subsequent years represent the period of a possible plant succession.

The herb layer differs with the age of rills. Considering the life forms, chamaephytes were found only in the rills older than 10 years, and the occurrence of phanerophytes grows with the age of rills. Differences of growth forms between age groups are not significant. Species richness significantly rises with the age of rills (R = 0,54; p = 0,05, Figure 4). Correlation between plant cover and the age of rills is not significant. In most of rills younger than 3 years, the cover was low (10 – 15 percent); however, in older rills, the effect rill age of rills on the cover (ranging between 26 and 80 percent) is not evident (Figure 4).

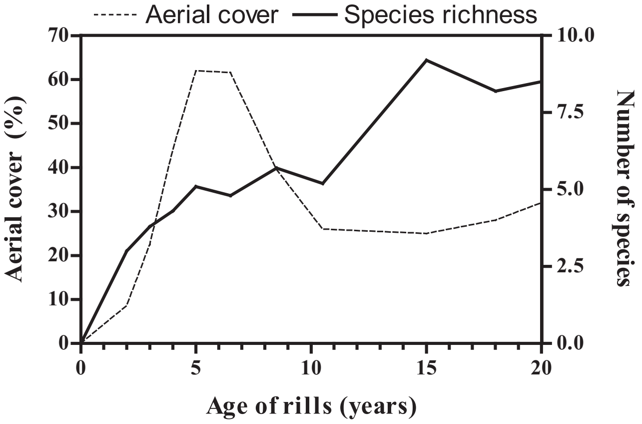

Figure 4. Effects of the time (rill age) on plant cover (%) and number of species (species richness) in erosion rills.

4. Conclusions

In the upper plain of the Jizera Mts. (gentle slopes to 12 – 14^o), the potential annual loss of soil estimated by USLE varies from 0.2 mm (mature spruce stands) to 1.2 mm (conversion to grass). During the last 20 years (with dieback and clear-cut of spruce stands), the invasive grass has become the dominant cover of the soil. Negligible sheet erosion has been observed in run-off plots covered by herbaceous layers; however, very important soil loss occurred in erosion rills originated by skidding of timber (0.3 - 1.2 mm/year). The spontaneous succession of herb vegetation seems to be highly important for stabilisation and reclamation of erosion rills.

The main parameter affecting the recovery of rills is their depth (reflecting the intensity of soil erosion as a superposition of erosion factors influenced by harvest technologies: length, slope, soil erodibility, and intensity of skidding). The rising depth of rills is related to the lower cover of vegetation, a drop in species richness, a higher proportion of hemicryptophytes, and the plants forming clusters or bunches. As these plants do not have a good ability to cover the soil surface and to protect it against erosion, the erosion process may be prolonged.

Concerning the age of rills, a positive significant correlation was found to species richness, and the occurrence of phanerophytes and chamaephytes. The results indicate the positive impact of time on the occurrence of plant forming clusters, and the negative effect on plants forming tillers.

From the point of view of soil protection, more; but shallow rills (depth from 0 to 0.25 m) can recover much better than only few deep rills (deeper than 0.5 m). The shallow rills can re-grow quite fast, but in the deep rills, the spontaneous succession is retarded or even hardly possible. So, the rills deeper than 0.5 m require the application of reclamation techniques (stabilisation of the profile by check-dams etc.). It is evident, that environmental friendly forest practices may avoid an increase in soil erosion from the harvest of timber.

5. Acknowledgements

This research has been supported by the Earthwatch Institute (Boston, USA, 1991-2003: project "Mountain Waters of Bohemia") and by the Czech Grant Agency (Prague, Czech Republic, 2001-2003: project 103/01/0322).

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LEACHING OF NITROGEN FROM UPLAND FOREST-REGENERATION SITES INTO WETLAND AREAS

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KEYWORD/ABSTRACT: Groundwater /nitrogen / clear-cutting / natural regeneration / pine / spruce

The concentration of nitrate and ammonium nitrogen in the groundwater was investigated one year before, and during seventeen years after, clear-cutting at the Pahalouhi experimental site at Kivesvaara, located in the middle-boreal coniferous forest zone in Finland (64°28 'N, 27°33 'E). The effect of natural regeneration of Norway spruce (*Picea abies*) and Scots pine (*Pinus silvestris*) has been investigated at the same experimental site since 2002, when the Pahalouhi experimental field was supplemented with the inclusion of natural regeneration. All the treatments caused a rise in nitrate nitrogen concentrations, but leaching during the first two years from natural regeneration was clearly less compared with that observed following clear-cutting and planting. Having been initially virtually zero, the concentrations of nitrate nitrogen continued to rise for 5-7 years, reaching 500-700 µg/1 at their highest, after which they began to fall. The concentrations were still high seventeen years after clear-cutting, which constituted a situation not observed earlier. Compared with nitrate, there was no corresponding ammonium nitrogen leaching.

1. Introduction

The effect of forest regeneration on watercourses depends on the regeneration method used. Clear-cutting and site preparation cause the greatest changes in site conditions and to the environment. The oldest research carried out within the boreal coniferous forest zone on the leaching of nutrients into watercourses was conducted in Sweden in the early 1970s [1], [2]. In Finland, the effect of clear-cutting and site preparation on the

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quality of surface runoff has been monitored since 1974 [3] and on the leaching of nutrients from entire catchment areas since 1983 [4]. The leaching of nutrients into the groundwater after forest regeneration has been monitored since 1986 [5].

In several studies, nutrient leaching into surface waters has been found to be a few years in duration. Long-term monitoring has revealed that after regeneration cutting, nitrate nitrogen is leached into the groundwater for more than 12 years [5]. Also, the timing of maximum leaching of nutrients into the groundwater following cutting takes place a few years later compared with leaching into surface water.

The main principle is for forestry practitioners to try to ensure that potential harm caused by forestry to watercourses and the aquatic organisms be minimised. This can be achieved in two basically different ways: by using sufficiently wide uncut buffer zones or slightly thinned buffer zones, or by stopping leached nutrients and solid matter by means of overland-flow fields before they actually enter water systems [6]. Compared with surface runoff, the leaching of nutrients into the groundwater is more difficult to prevent. Within the clearcut area itself it seems to last for a long time [5], which is why it is important to study the effects of different regeneration methods on groundwater quality.

The aim of this study is to investigate the effects of natural regeneration of Scots pine *(Pinus silvestris)* and Norway spruce (*Picea abies*) on the leaching of nitrogen into the groundwater during the first few years after cutting. The results are compared with long-term monitoring information collected from the same research area. The new information can be utilized when developing ecologically sustainable forest management methods as well as when taking action to protect drinking water stored in large aquifers.

2. Material and methods

The experimental area, Pahalouhi, located at 64°28'N, 27°33'E, is representative of the prevailing conditions in the middle-boreal coniferous forest zone. The site type is dryish upland. The total amount of logs and pulpwood harvested was 141 m^3/ha, of which Scots pine *(Pinu. silvestris)* made up 51%, Norway spruce *(Picea abies*) 46% and birch *(Betula pendula, Betula pubescens*) 3%. The cutting was carried out in 1986 using a harvester. Monitoring the quality of the groundwater was commenced the year before cutting in 1985. The plots were planted with Scots pine *(Pinus* *sylvestris*) making use of manually made scalps in the spring of 1987. The soil ranged from sand to sandy till.

A total of 24 groundwater wells were set up within the Pahalouhi experimental area. They consisted of plastic piping varying from 4-6 m in length with perforations in the lowermost 1.5 m and a plug seal the bottom. Four treatment areas were established initially: clear-cutting with cutting waste not collected, clear-cutting with cutting waste collected, ploughed treatment, and an uncut control. In 2001, the Pahalouhi experiment was extended to include natural regeneration by using shelter-wood cutting of spruce in part of the old control area and seed-tree cutting in the area adjacent to the old clear-cutting in 1986. These areas had 11 new wells set up in the autumn of 2001. The amount of shelter-wood was 300 stems per ha while seed-trees numbered 50 stems per ha. The shelter-wood area was not treated with site preparation to assist the emergence of seedlings while the seed-tree area was harrowed; these methods are in current use in Finnish forestry. The new groundwater wells were set up within these areas in 2001.

Water samples were taken annually from each well once a month from May to October. A low-pressure pump was used to sample the groundwater. Chemical analyses were carried out at the Muhos Research Station following standard methods. This paper presents the results for nitrate nitrogen concentration measurements in the clear-cutting and control areas over the period 1985-2003 and in the natural regeneration areas for the first two years.

3. Results

3.1. CLEAR-CUTTING AND PLANTING

Nitrate nitrogen concentrations at the site were initially 30-50 μg/1 and they continued to rise for 4-5 years following clear-cutting, reaching their peak of over 500 μg/1 in 1990 (Figure 1). The concentrations were still above the initial level for more than seventeen years after cutting. Contrary to nitrate nitrogen behaviour, the results for ammonium nitrogen do not indicate a corresponding increase as a result of this or any other treatment.

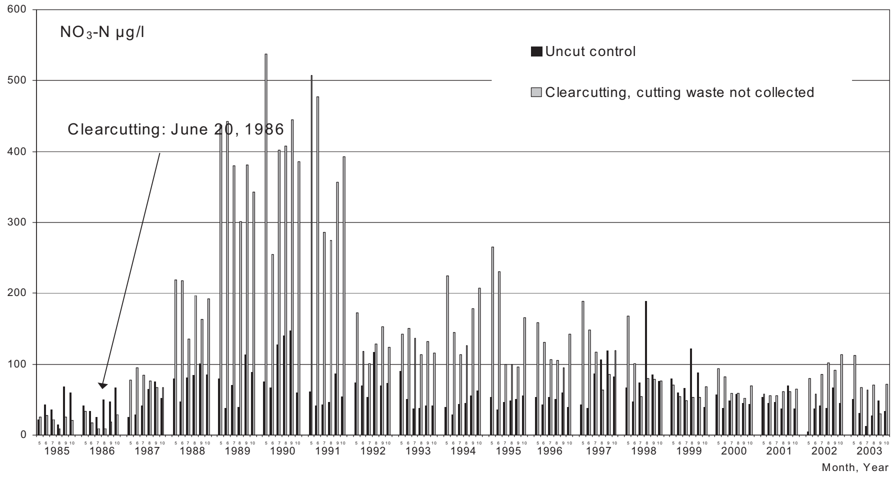

Figure 1. The effect of clear cutting and planting on the leaching of nitrate nitrogen into the groundwater in 1986-2003. Dark columns represent the values from the control area. Each year, samples were collected once -monthly from May to October.

3.2. NITROGEN FLOW IN GROUNDWATER OUTSIDE THE SITE

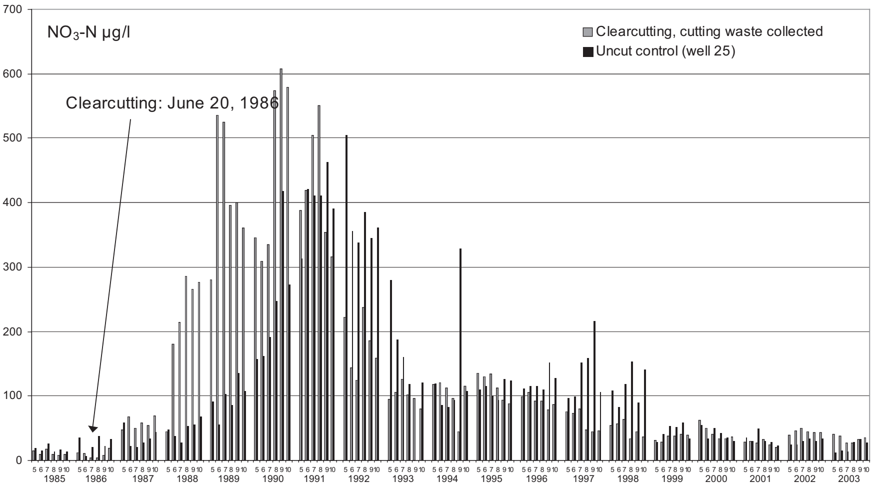

Figure 2. Nitrate nitrogen flow in the groundwater.

The slope of the site was lightly inclined towards this well, which makes it possible to follow the movement of nutrients. The results (Figure 2.) show that nitrate nitrogen is moving towards the wetlands further down,

3.3. NATURAL REGENERATION OF SPRUCE

Shelter-wood cutting was done in the late autumn of 2001. The results from the first two years indicate that leaching increased during the second year (Figure 3), but not as much as after clear-cutting (Figure 1) during the corresponding time. In the first year, there was a statistically significant difference (*p* 0.014) between shelter-wood cutting and the uncut control, but not in the second year (*p* 0.79).

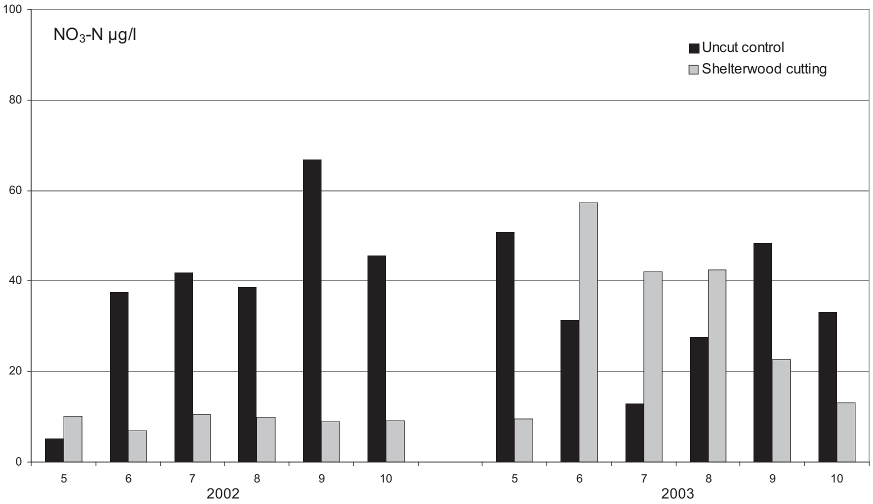

Figure 3. Nitrate nitrogen concentrations in the groundwater during the first two years after shelterwood cutting of Norway spruce.

3.4. NATURAL REGENERATION OF SCOTS PINE

Following seed-tree cutting, the regeneration area was divided into two plots, one with and the other without site preparation. A small area with one well was left in the uncut state (Figure 1). There were statistically significant differences (*p 0,00)* between all treatments in both years (Figure 4). The highest concentrations were observed in the harrowed plots and the lowest values in the uncut area. A gradual increase towards the autumn was noted. The results clearly show that natural regeneration increased nitrate leaching into the groundwater, especially with site preparation included, but once again the values were far lower than after clear-cutting (Figure 1) within the corresponding period of time. In the clear-cutting area, the maximum concentrations during the second year were between 100–200 µg/l while in the area involving natural regeneration they all were clearly below100 µg/l with and without site preparation.

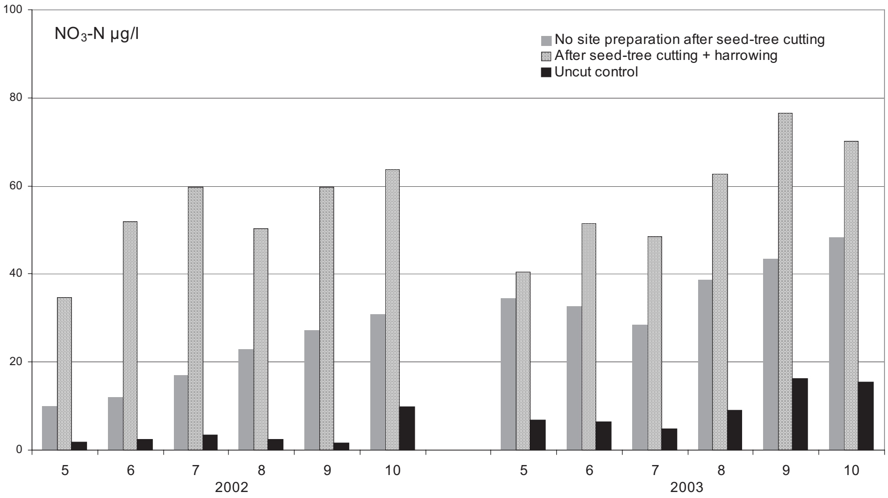

Figure 4. Nitrate nitrogen concentrations in the groundwater during the first two years after seed-tree cutting of Scots pine.

4. Discussion

The Muhos Research Station of the Finnish Forest Research Institute has established several experimental fields at Kivesvaara, northern Finland, dedicated to forest regeneration and its environmental effects [3], [5], [7], [8]. The research data collected in this study comprises some of Finland's oldest and most extensive monitoring data on the leaching of nutrients into surface waters and groundwater as caused by forest regeneration when applying clear-cutting. No site preparation was used in the clear-cutting area.

The effects of clear-cutting on nitrate nitrogen concentrations in surface water have been shown to last only a few years [1], [3], [4], but the long-term property of increasing groundwater concentrations, which have persisted much longer than 10 years, have not been reported in earlier studies

[2], [9]. Clear-cutting increases the input of precipitation, but in northern areas this cannot be the main reason for the higher values. The greater part of the increased concentrations is due to the decomposition of cutting waste and humus, but the reasons for long-lasting leaching need further investigation. There was no increase in ammonium concentrations, as was also observed in boreal areas by Rusanen et al. [9].

Nitrate nitrogen seems to be the foremost nutrient leached into the groundwater as a consequence of forestry operations. The impacts of forest regeneration on aquatic ecosystems can be prevented quite effectively as regards surface waters, but preventing the impacts on groundwater is far more difficult. As our knowledge in this matter based on experimental research was formerly lacking, it is not possible to go into any detail concerning preventative methods. An essential aspect would appear to be that the biological cycling of nutrients on regeneration sites should continue to function so as to minimise leaching of nutrients [10].

The fresh results provided by this study indicate that natural regeneration causes less nitrogen leaching than clear-cutting. The results represent, however, a very brief period of time, and we do not know the long-term effects as yet. However, in order that we might take good care of the forest environment and apply ecologically sustainable forestry, it is worth recommending that natural regeneration be used whenever it is economically feasible. This complies also with the environmental guidelines set for forestry. As an aspect of environmentally sound silviculture, special attention has been given to the effects on watercourses and the protection of water ecosystems. The central objective of watercourse protection guidelines is to preserve the waters in good condition and protect the biodiversity of aquatic and adjacent ecosystems

5. Acknowledgement

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HYDROLOGY OF DISTURBED PEAT-LAND, HEADS OF THE VALLEYS, WALES

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KEYWORDS/ABSTRACT: uplands / peat lands / hydrological role / land use conversion / reclaimed opencast coal-land.

Runoff from peat land is supposed to be dominated by surface and near surface flows causing large flood peaks. However, Waunafon's degraded valley fen peat moorland includes organic layers up to 0.5m deep that are unsaturated in summer. So while, overland flow may be affected by rainfall onto saturated ponds, runoff in soil pipes, and through channel incised between the tufts of heath, this degraded peat land has a significant storage capacity in summer and commensurate capacity for seasonal flood attenuation.

1. Introduction

Many British rivers drain extensive areas of headwater peat and wetland [23]. The exact hydrological role of these lands is not well understood but it is thought that they are highly productive of storm runoff, when compared to other catchments, and relatively unproductive of base flow [3,10]. Across the 100 km reach of the Heads of the Valleys Region of South Wales, land that was originally moorland and peat bog has been replaced by grazing, urban and industrial land uses. Where peat wetlands and organic soils used to overlie the northern outcrops of the coalfield, these lands have been replaced by deep coal-mine or surface coal-mine spoils, often mantled with the thin layers of artificial topsoil employed in

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the name of land reclamation [4]. The question asked in this report is: what are the hydrological functions of such wetland areas? This is investigated through the field monitoring of rainfall and runoff processes on one of the few surviving areas of semi-natural peat bog in the region, Waunafon Bog, technically a valley fen on Milfraen Moor [14].

2. Previous Research

The classic model of peat hydrology distinguishes between an actively growing, periodically aerated, upper layer (acrotelm), which extends down to the deepest level of water-table fluctuation and the permanently saturated, anaerobic layer (catotelm) beneath; [10,11,21]. Water movement through the upper layer is very rapid, often equivalent to surface runoff, and sometimes 4-5 orders of magnitude greater than that below [21]. In incised peat lands, much flow may be transmitted through large soil pipe systems [24]. Holden and Burt [11] report from the northern Pennines that saturation excess overland flow and near surface through-flow in the acrotelm dominate runoff and that very little is produced from the peat matrix below. They report that, en route to the stream, perhaps 35% of flow moves through the macro-pore network, 20% as shallow through-flow, 10% through soil pipes, and 80% as saturation excess overland flow – the total of 145% reflecting that waters may move through several pathways. Elsewhere, they suggest that >99% of the flow collected in their runoff troughs was generated by flow within 50mm of the surface [10]. They also emphasise the spatial variability and complexity of the water flow paths in complex blanket bog mantled catchments.

3. Historical Background

This catchment lies on the margins of the UNESCO World Heritage industrial landscape area at Blaenavon, Torfaen, on the borders of Torfaen and Blaenau Gwent County Boroughs, and on the margins of Wales' first opencast coal mine complex at Pwll Du, which produced $1.87*10^6$ Mg of coal between 26th May, 1943 and 1950 [7]. In 1989-1992, Waunafon Moor was central to a controversy concerning plans for a new $5*10^6$ Mg, 12.5 year, Pwll Du Opencast Coal mine, which was proposed by the British Coal Corporation's Opencast Executive [2]. This proposal was based on extensive geological and environmental survey, most of which was intended to prove the economic viability of mining coal seams that had already been heavily worked by deep coal mines. However, some work also was conducted with regard to the environmental impacts of the project and feasibility of land reclamation when mining was finished. When the project was called to Public Inquiry, much of this entered the public domain. However, after the longest running Public Inquiry in the history of Welsh planning, the proposal was denied by the Secretary of State for Wales. Despite this, after British Coal was privatised, the land that includes Waunafon Moor was sold with a note to the effect that it had the potential for future opencast coal-mining [4]. This hydrological study, which antedates the declaration of the proposal for surface coal-mining, was conducted independently of the mining operations and was continued for some years after the mining proposal was declined. However, it has benefited from the vast output of technical information produced in connection with the development of the plan for the Pwll Du Opencast mine.

4. Site Description

The Waunafon catchment (51^{o}47'30"N03^{o}9'30"W) covers cca.28 hectares at an altitude of 414-440 m above msl in the headwaters of the Afon Lwyd Valley [13]. The basin's longest flow line is about 800 m, it is about 600m at its widest, while the basin slopes at about 5% grade (< 3^o) to the southeast. This is land is managed as Common and grazed by cattle, sheep and ponies all the year round. It includes substantial areas affected by the out-wash of colliery wastes from the former Milfraen Colliery, which operated until the late 1920s, then later from its abandoned spoil tips and from their reclamation in the 1980s.

About two thirds of the basin is classable as true wetland, 29% of the catchment area is mire dominated by *Juncus effusus* and *Sphagnum recurvum*, and another 31% is mire dominated by *Molinia caerulea* and *Calluna vulgaris*. In the lower basin, the vegetation is developed on a hummocky microrelief of cylindrical or hemispherical hummocks upon a flat surface [21]. Unvegetated exposed peat covers about 6% of the area and another 1-2% is taken up by an *Eriophorum angustifolium* (Cotton grass) pool. The remaining third of the catchment, mainly the higher and more disturbed ground close to the western site margin track, is grassland. From this, perhaps 10% dominated by *Molinia caerulea,* and the balance (23%) by different combinations of *Agrostis canina, A. capillaris, Festuca ovina* and tufts of *Nardus stricta* [12]. Humphries [12] prefers to refer to these communities as heath rather than mire, believing that the vegetation has colonised the peat deposits in recent times following the drying out of the bog.

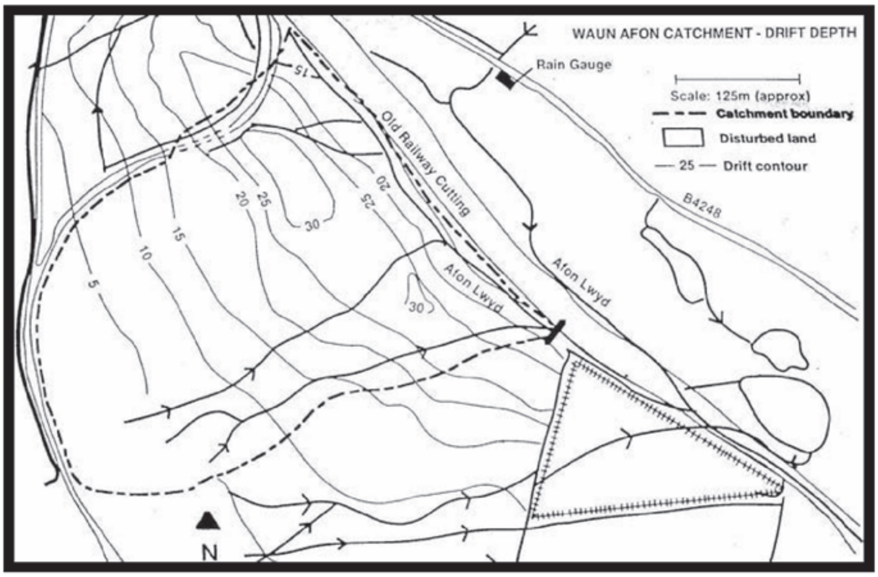

Figure 1. Buried channel beneath Quaternary 'drift' deposits at Waunafon.

The catchment is underlain by Carboniferous age, Lower Coal Measure strata, mainly mudstones with some sandstones and coals seams. Structurally, these rocks dip southwest between two major faults, the Carreg Maen Taro Fault and Blaenavon Fault, which run NW to SE across the area, more or less parallel to the Afon Lwyd thalweg [25]. However, hydrological connection with these bedrock layers is mitigated because the whole site is mantled by largely impermeable clays derived from the weathered mudstones [25]. The surface contours of this Quaternary clay contain a former channel of the Afon Lwyd, which also crosses the catchment from northwest to southeast, at depths of up to 6m below the present land surface (Figure 1). During the Public Inquiry, the Ove Arup view that the upper Afon Lwyd is fed mainly by surface water runoff with negligible ground water contribution, was contested by Gwent County Council who felt that the Waunafon Bog may make a significant contribution to the base flows in the river [18,25,26]. They also pointed out that the hydrology of this bog, technically a valley fen because parts may receive ground water contributions from Coety Mountain upslope, was unexplored [18].

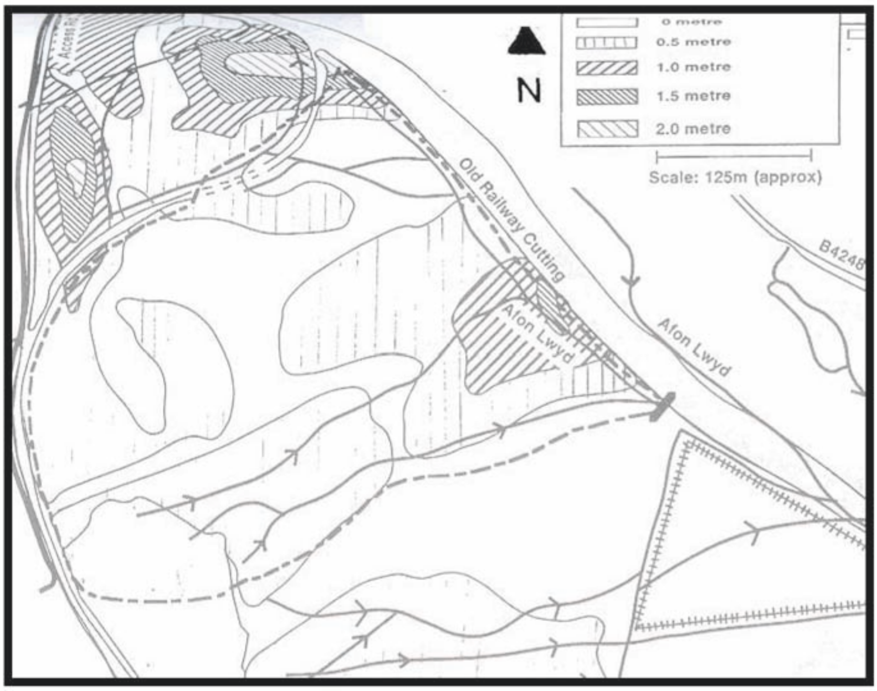

Figure 2. Minimum depth of peat deposits at Waunafon.

Maps presented by Humphries [12] suggest that the average depth of peat across the catchment is about 0.6m, with peat depths >1.0m on 12% of the basin, < 0.25m across 43% and between 0.5 and 1.0m across 45% (Figure 2). Seven boreholes were sunk into the catchment to depths of 10-20 metres. This was work done for British Coal in connection with the proposed New Pwll Du Opencast Coal Mine [15,16]. Four boreholes (in the lower and middle part of the catchment) found depths of peat at 0.7-0.8m (Figure 2). One on the north-western margin records a depth of 6m, while two close to the former mineral railway line that skirts the northern and north-western boundaries of the catchment prove only 0.5m. In combination, these data suggest that the surface layer of the catchment contains around $17*10^3$ m^3 of peat. British Coal surveyors estimated that the whole area of the Waunafon Bog contains about $242*10^3 m^3$ of peat including several areas that were in a supersaturated condition [15,16].

5. Methods

The catchment selected for study is located on Waunafon Bog at Milfraen. It comprises 28 ha of open moorland underlain by peat soils and containing pockets of peat up to 6m deep. An OTT R16 stage recorder was established behind a v-notch weir on this catchment, where the channel joined a ditch drain adjacent to the railway cutting. For purposes of comparison, flows were converted into l.sec.ha. The weir capacity (500 l.sec) seems never to have been exceeded through the whole period of observation. Hydrological monitoring on the site began in 1985 and continued full time until 1988 then sporadically until 1999. Throughout the project, the OTT R16 stage recorder operated with extreme reliability. A Lambrecht, WMO-standard, chart recording rain gauge established on the catchment margin proved much less effective. Sixty-one storm events were selected for analysis using the same criteria as Evans et al [5]. The storms spanned a range of flow conditions, they were single peaked, rainfall driven, and spread out, as far as possible, through the year. Finally, simple field infiltration measurements were collected using a 100-mm single ring infiltrometer and this was supported by soil physical testing [14].

6. Results

Flow was recorded for 76% of the period 1985-1988 on the moorland catchment [3]. Studies of a neighbouring catchment, where peat soils have been replaced by pasture after surface mining, recorded flow for only 20-25% of the same period [5]. Researchers agree that the runoff generation on peaty organic land is controlled by a thin (< 100mm) fibrous upper layer, while lower layers are permanently saturated and their waters relatively slow moving [9, 19, 23].

Measured summer final infiltration rates on the Waunafon peat land ranged from 1510 mm.hr^{-1} in the topsoil to 214 mm.hr^{-1} in subsoil at depths of 500 mm, but still above the saturated layer. Robinson and Newson [20] recorded a similar wide range in an upland moorland catchment. It is suggested that, while the hydraulic conductivity of peat soils is often high, they can become hydrophobic in dry weather, which could increase the variability of infiltration rates [1]. Spikes in the data from these tests record the presence of macropores/soil pipes/fissures [6]. Holden and Burt [10] suggest that near-surface pipe-flow may carry 10% of all flow on peat catchments.

Peak Flow (l.sec)		**0.347 (0.032)**	**0.530 (>0.0005)**
Rainfall to Peak flow (mm)	**0.347 (0.032)**		0.252 (0.094)
Time to Peak flow (hrs)	0.099 (0.304)	**0.483 (0.004)**	0.246 (0.099)

Table 1. Correlation of flood peak control variables in an upland peat catchment (Waunafon).

Detailed study of 61 flood events found that the average flood peak on the peaty moorland was 2.45 (sd. 2.31) l.sec.ha. The average flood peak was generated by rainfall depositing 10.29 (sd. 6.2) mm through 5.94 (sd.2.17) hours. Correlation analysis (Table 1) shows that there is a strong significant correlation between the size of the peak flow and rainfall recorded in the 48 hours before the event and a weaker, still significant, correlation between the amount of rainfall and the size of the flood peak. The time between the start of the rainfall event and the flood peak was not correlated to its size but was strongly linked to the amount of rainfall.

Seasonality was a conspicuous attribute of the flow from Waunafon. If its flood peaks are divided between the four seasons, then the data from the moor generates a significant correlation (r: 0.489; $p<0.05$). The peaty catchment produces its highest flood peaks in the winter and smallest in the summer. This indicates that lowering of the water table in summer creates greater storage for rainwater.

7. Discussion

Wetlands are said to have three landscape functions: flood mitigation, although this is contested for the specific case of peaty upland wetlands, aquifer recharge, although except where there is a large edge to area ratio, wetland make poor aquifers and allow little base flow, and water quality, where they often act as sinks for organic and inorganic chemicals [3,19,24].

The results from Waunafon contradict most of these assertions. Its degraded peats carry a substantial sediment load compared to neighbouring pasture on former opencast coal-lands and frequently yield discoloured water. They also sustain flow for more three times as long through the year [13].

Evans et al [5], who worked to the north in Cumbria, found that water table recession below 50mm was unusual between September and May, but that in dry summers it dipped below 200-250cm for short periods. However, Burt [3] confirms that water tables may sink below 500mm in summer in British headwater peat lands but remain close to the surface in winter and this is certainly the case here.

Much of Waunafon's overland flow is generated from saturated ponds and through a system of channels that weave between the tufts of heath in the lower catchment. Blanket peat areas, their runoff dominated by near and surface flows, are supposed to be typified by flashy hydrographs and large storm flood peaks [3,10,11,22].

Studies within small peat headwater catchments of the Scottish River Dee confirm the relative unimportance of groundwater contributions to flow and also of riparian influences – by and large the peat land runoff flows directly into drains and channels [22]. However, in this valley fen, there are undefined possible connections with ground waters flowing beneath the impermeable clay layers that underlie the basin. Treherne [25,26] notes that, even when surface flows from the Waunafon area were zero, the flow at Blaenavon town, approximately 3 km downstream was 19 l.sec. due to over flow from flooded deep coal-mine workings. However, as Figure 1 shows, beneath the current land-surface of Quaternary sands and clays, a buried glacial channel crosses the catchment from northeast to southwest. It is not clear how much ground water seeps from the basin along this fossil channel system (Figure 1).

Seven boreholes were sunk into the catchment to depths of 10-20m in connection with the estimation of the volumes of soil-forming materials that would be available for the restoration of the proposed New Pwll Du Opencast Coal Mine [15,16]. These prove wide variations in the depth of peat across the basin (Figure 2). The deepest pocket located was 6m while two boreholes on the northern and north-western boundaries of the catchment prove only 0.5m. These two boreholes also find the glacial clays at depths of about 4m with fine sandy clay loamy materials between. In the deep peat pocket, a 0.5m layer of sandy and sandy clay loam separates the peat from the glacial clays at 6.5m depth. By contrast, four boreholes of the lower catchment found peat resting directly upon glacial clay layers 1.5 to 5m thick, although there are more permeable sandy and sandy-clay layers at greater depths. The possibility of a hydrological connection between the surface sandy-clays and those below the glacial clays cannot be discounted.

Holden and Burt [10] argue that because undisturbed upland blanket peats are surface and near surface flow systems, they respond very quickly to rainfall (2.1-3.2 hours mean rainfall to peak in basins of 1,140 ha, 83 ha. and 44 ha respectively) and so tend to be sources of flooding rather than attenuators of flow. The disturbed peat land at Waunafon, despite the catchment being just 28 ha, took almost 6 hours to reach peak flow after rainfall, compared to only 4.8 hours on the neighbouring pasture [14].

Treherne [26] argues that the Waunafon Bog provides no significant storage or attenuation for the Afon Lwyd River, because water storage is restricted to shallow ponds that develop on the surface of the bog while the underlying peat is saturated and has little capacity to absorb additional water. However, this is certainly not the case in summer, when the lowered water table creates significant storage capacity in the drained upper 0.5m of peat. Comparison of flows from Waunafon with those from a neighbouring catchment on pasture reclaimed after coal-mining find that, in summer, the ratio between flood peaks increases from an average of about 1:3 based on unit hydrographs to more than 1:10 in summer [13,14]. So, this degraded peat land does function as summer flood attenuator.

How significant this may be is unclear. Soulsby et al. [22] note that the impacts of headwater wetlands disappear quickly as catchments are studied at a larger scales. Here, the peat wetland occupies only 7% of the catchment upstream of the neighbouring town of Blaenavon, so the impact is likely to be minimal.

8. Conclusion

The research literature suggests that runoff from peat land is dominated by surface and near surface flows that generate flashy hydrographs and large storm flood peaks [3,10,11,22]. However, Waunafon's valley fen peat moorland includes organic layers up to 0.5m deep which are unsaturated in summer. Here, much overland flow may be generated from rainfall that falls onto saturated ponds and runs off in the system of channels that weave between the tufts of heath in the lower catchment. In addition, runoff may be affected by complex relationships between soil pipe systems, surface ponding and undefined possible connections with ground waters flowing beneath the clay layers that floor this degraded wetland [14]. However, this peat land has a significant storage capacity in summer and a commensurate capacity for seasonal flood attenuation, although, in this case, the effects may be very local and small scale.

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ESTIMATION OF WATER BUDGET IN THE FORESTED PEAT-LANDS OF WESTERN IRELAND

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KEYWORDS / ABSTRACT: Evapotranspiration / interception / peat-lands

Aspects of the hydrology of a small blanket peat catchment in Cloosh forest, County Galway, were investigated focusing on evapotranspiration during one calendar year in 1996, which was compared with the lysimetric values obtained from the nearest weather station. Using monthly rainfall data from the weather station and published data for through fall and stem flow, a value for the net amount of water reaching the soil was calculated. Runoff was measured using the STARFLOW recorder. It was found that the net effective water was equal to runoff in fully saturated blanket peat. The Penman-Monteith equation was used to calculate the evapotranspiration in the Cloosh catchment and this was compared the water balance equations. The change in the evapotranspiration values were attributed to the difference in through-flow and stem-flow.

1. Introduction

The scientific study of evaporation and transpiration has been underway for many years. Historical review by Rosenberg et al [10], traces research back to Aristotle who concluded in the Fourth Century B.C., that wind is more influential in evaporation than the sun. Direct evaporation from the soil and transpiration occur simultaneously in nature and there is no easy way to distinguish the water vapour produced by these processes. Thus the term evapotranspiration is used to describe the total process of water transfer into the atmosphere from vegetated land surfaces.

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Evapotranspiration has been widely used as a tool in geographic studies of world climate and in predicting the water needs in dry land and irrigation agriculture. Recently, its use has been extended to studies on the water movement and glacial changes in the temperate regions. The studies on evapotranspiration have further brought about the term potential evapotranspiration, which can be defined as the evaporation from an extended surface of a short green crop which fully shades the ground, exerts little or negligible resistance to the flow of water and is always filled with water. Plant factors affecting evapotranspiration:

- Interception of rainfall by the canopy: interception can be defined as the capture and subsequent evaporation of part of the rainfall by vegetative canopy or other structure, and thus not reaching the ‘protected area’ [9]. Interception depends on factors like intensity, amount and distribution of precipitation, evaporative flux and the shape, stand, size and number of leaves.
- The morphology of a plant: the size of the leaf maybe important since larger leaves tend to be less efficient in dissipating heat through convective transfer and will, therefore, have more energy available for evaporation than smaller leaves. Other morphological features, including pubescence, colour, leaf shape and presence of awns and other specialised structures may influence the amount of water used by plants.
- Stomatal resistance: considerable efforts have been devoted to understanding the manner in which stomates control transpiration. Hansen [5] has shown that transpiration in Italian Rye grass is a curvilinear function of stomatal resistance or a linear function of stomatal conductance.
- Transpiration ratio: transpiration ratio is the ratio of water transpired to dry matter produced, and is characteristic of the thinking that regards the water requirement of plants as dominantly a biological phenomenon. Transpiration ratio is sometimes affected by the changes in climatic conditions.

2. Importance of the study of water budget in forested peat lands of Ireland

Considerable efforts have been devoted to understanding and estimating evapotranspiration from forests. Since they are aerodynamically rough, and due to their size and distribution of foliage throughout their canopies, significant quantities of sensible heat are exchanged between the air and leaves and even during humid climates sensible heat advection can be an important source of energy for transpiration in forests. Lysimeter studies have been carried out to measure evapotranspiration from salt cedar[4], from Douglas fir [3] or from spruce [2]**.** The studies, however, can't reveal the shortage in the overall water budget and the reasons is the fact that intercepted water can be twice that which has been transpired [2], [8]. Thus, the importance of the study is relevant to the context that the correct estimation of water budget is a difficult task and empirical methods should be adopted to estimate the real count.

In the catchments of Ireland, evapotranspiration is estimated using the following methods:

- Lysimeters
- Empirical formulas (for example Penman-Monteith equation)

The disadvantage of the lysimeteric method is the 'oasis effect'. In dry weather, the soil in the surrounding area is much drier than that in the lysimeter and there is large increase in evaporation from it.

In Ireland, the Penman-Monteith equation is commonly used for the estimation of potential evapotranspiration in forest areas. The shortcoming of the Penman-Monteith equation is that it does not consider the water loss by interception (stem-flow and through-flow) in a forest catchment and sometimes overestimates the water budget. Thus, this study focuses on aspects covering stem-flow, through-fall and interception. The empirical methods are compared with results of the water balance equation.

3. Materials and Methods

3.1. SITE LOCATION

The experiment was carried out in a small forested peatland in the Cloosh forest, County Galway. The experimental plot was situated in a part of Cloosh forest that has been used for several years as a monitoring plot by the forest ecosystem research group (FERG). The forest species grown are mostly Spruce (*Picea sitchensis*) and lodge pole pine (*Pinus contorta*). A small man-made drain was constructed to measure the water flow from the experiment plot and it was judged that all the excess water coming into this plot was collected in this drain.

3.2. MATERIALS USED

The drain was fitted with an automatic flow recorder, complete with a data logger. Meteorological parameters were recorded by a small portable weather station which was installed in the open part of the forest. It uses an MM 900 data logger to store information from the sensors. The rain gauge used is the tipping bucket type and is connected to the weather station and the MM 900 data logger which records the Monthly mean rain data. The weather station also has a wind speed recorder and maximum-minimum temperature recorders. The humidity is measured using the wet bulb thermometer which is also a part of the weather station.

3.3. METHODOLOGY

The methods used for the estimation of evapotranspiration were: a) water balance method, and b) empirical method.

3.3.1. Water balance method

In the water balance method, Rainfall (P), Interception (I), Storage water (Δ S), Drainage (D) and runoff (R) were taken into consideration:

$$ET = P - (\Delta S + R + D) \qquad (1)$$

The soil being saturated by blanket peat, both D and Δ S are taken as Zero. Hence the equation can be simplified as:

$$ET = P - R \qquad (2)$$

Values of P recorded ‘in the open’ must be modified to account for the interception of rainfall by the dense canopy of the forested plot. Values of the interception percentage for each month of precipitation for the dense coniferous forest in Cloosh are available [1]. These show that interception varies with month and rainfall intensity but reasonable values can be obtained by averaging the interception factor across a number of years (Figure 1).

Hence in Equation (2) P is replaced by Pc, where:

$$Pc = P - (I \times P) \qquad (3)$$

The interception percentage can be obtained by subtracting the water obtained by stem-flow and through-fall and this expressed as a percentage to the rainfall. Than, the equation can be written as:

$$I = P - (TF + SF)/P \times 100 \quad \ldots\ldots(4)$$

where TF = through-flow, and SF = stem-flow.

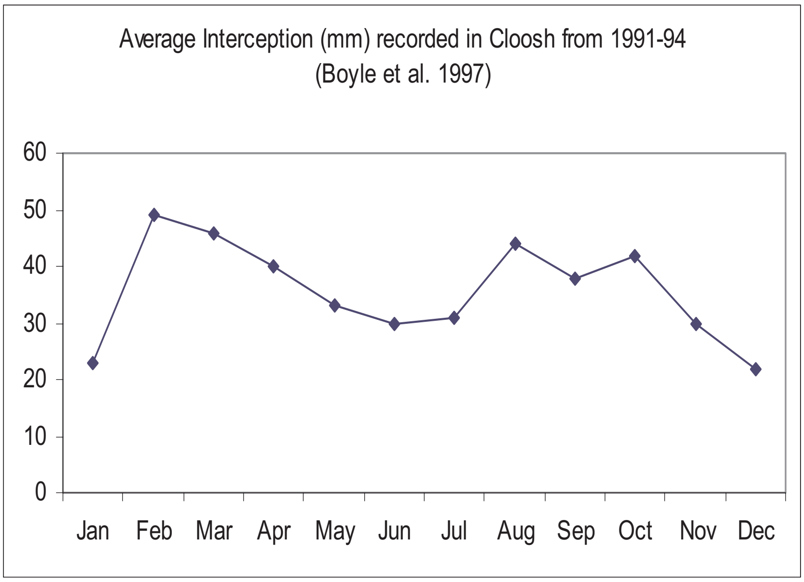

Figure 1. Average interception (mm) recorded in the Cloosh forest in 1991-1994.

3.3.1. Empirical method

The Penman-Monteith method [7] was used to calculate evapo-transpiration empirically. The parameters used are: maximum and minimum air temperatures, wind speed, sunshine hours, and humidity of the air. The Penman-Monteith equation is as follows:

$$Et = \frac{\Delta(Rn - G) + cp\rho a\dfrac{ea - ed}{ra}}{(\Delta + \delta)^{(\lambda)}} \quad \ldots\ldots(5)$$

where Et = evapotranspiration from a wet canopy (Kg/m^2), Δ = slope of saturation vapour pressure curve (Kpa/^{o}C), Rn = net radiation in J/m^2/d, G = heat flux density to the soil (J/m^2/d), cp = specific heat of dry air at constant pressure, ea = saturated vapour pressure at air temperature Ta, ed = prevailing vapour pressure at the same height as Ta, λ = Latent heat of water vaporisation (J/Kg), ra = aerodynamic resistance, g = psychrometric constant, ρa = density of moist air (Kg/m^3). The Et values were converted to mm/day by multiplying with 86,400.

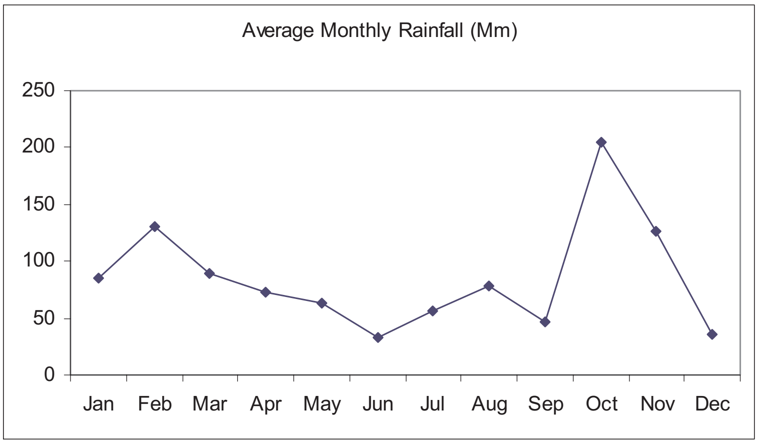

Figure 2. Average monthly rainfall recorded in Cloosh during the year 1996.

4. Results and discussion

The main source of water for the forest is rainfall. The average monthly rainfall data for the year 1996 in Cloosh is shown as Figure 2. Since a considerable proportion of the rainfall is captured by the forest canopy, the interception values were reduced from the actual rainfall and are termed as corrected rainfall Pc.

The results show that measured evapotranspiration values from the Cloosh catchment differ from those calculated from the Penman-Monteith equation. The potential evapotranspiration values obtained from the automatic weather station at the experiment site in Cloosh show similarity to the nearby Met-Eirenn station at Claremorris (synoptic weather station).

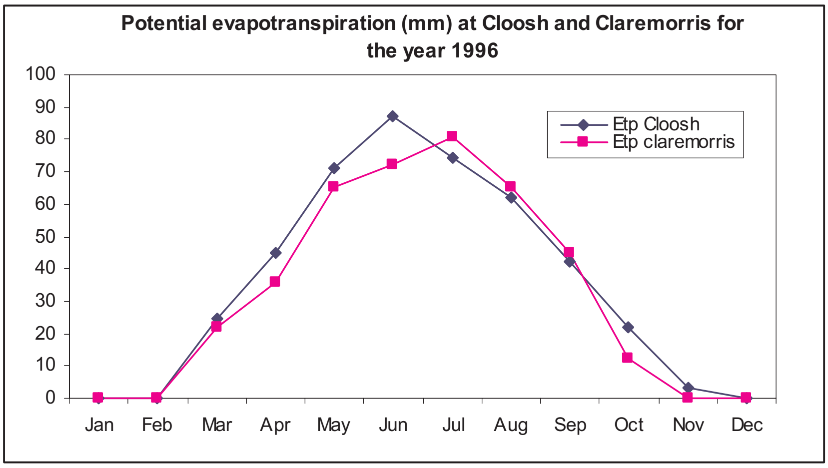

Figure 3. Comparison of potential evapotranspiration at Cloosh and the nearby Meteorological Station at Claremorris.

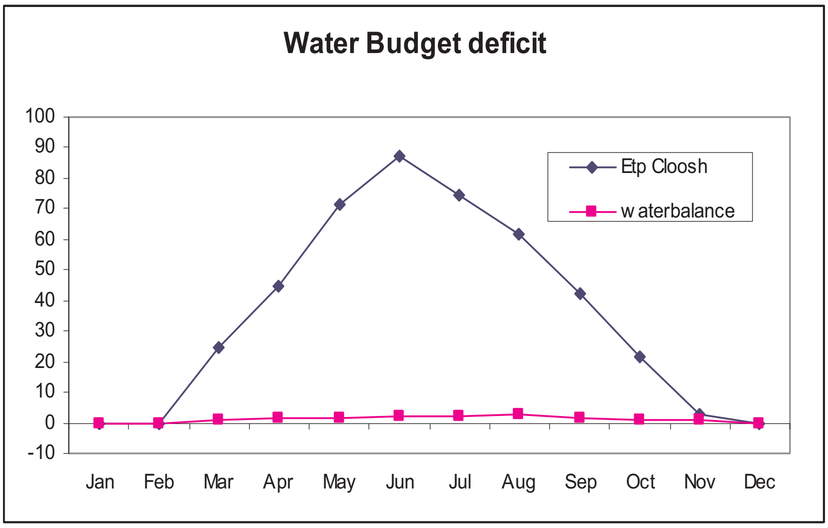

Figure 4. Differences in estimates of evapotranpiration (mm).

The climatic parameters, when applied to the Penman-Monteith equation, produce a fairly typical symmetrical curve, with 80/90mm of water passing through the evapo-transpirational pathway in June/July. Spring and autumn are half these values, while little or no water is transpired or evaporated in the period December/February (Figure 3).

The water balance method provides a completely different pattern to calculated by the Penman-Monteith equation (Figure 4). These differences in estimates of the evapotranspiration can be attributed to high interception by the forest canopy. In fact, much rain water is trapped by the canopy and so net precipitation is higher than that recorded in the open.

However, given the same amount of radiation, evaporation from this intercepted water was 3 times the average transpiration from a pine forest [6]. One reason is the fact that the canopy intercepts much radiation, and in a very dense forest, can prevent a lot of radiant energy from reaching the forest floor. For evaporation, there is a minimum energy for reaching the latent heat of vaporisation, which is not present during the early months of January, February and March and during the later years during October November and December. This is the reason for low evaporation from the forest floor during these months. The turbulent wind characteristic of forests is responsible, on the one hand, for reducing the energy available for evaporation but, on the other hand, ensures rapid removal of water vapour from exposed surfaces. This type of boundary layer conductance is most important when the canopy is wet and it means that there is more rapid evaporation of intercepted water from a forest canopy than from a smooth grass sword.

5. Conclusions

It is concluded that the value obtained for rainfall in the open and at ground level with standard gauges does not reflect the actual amount of rainfall captured by canopy of a mature Sitka spruce crop in western Ireland. The amount of water intercepted was found to be high and this was attributed to the evaporation taking place in the canopy and much less from the forest floor. Thus, the water balance equation needs to be modified to show the actual evapotranspiration taking place in the forest areas. However, the Penman-Monteith method is found to be suitable for the estimation of evapotranspiration in this Cloosh forest area, despite its limitations in estimating actual interception levels.

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ROLE OF THE PLANKTONIC COMMUNITIES IN THE REGULATION AND INDICATION OF EUTROFICATION PROCESSES IN SHALLOW MOUNTAIN WETLANDS

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Keywords/Abstract: landslide-dammed lake, eutrophication, planktonic communities, trophic state indices, Bulgaria

Protection and restoration of wetlands requires correct evaluation of their ecological and trophic state, i.e. detection and verification of appropriate indicators. The aim of the study is to clarify the role of planktonic communities (phytoplankton and bacterioplankton) in eutrophication processes in shallow landslide-dammed lakes and to apply routine indicators of eutrophication processes for a case study of Dragichevo lake. From May 2001 through September 2002 a bathometric map and map of macrophyte distributions was constructed, changes in the main hydrochemical parameters, phyto- and bacterioplankton were tracked, and the Carson's trophic state index determined. The results suggested that re-suspension processes and active interaction between sediments and water significantly influence both the plankton communities and chemical parameters of these wetlands.

1. Introduction

The protection and restoration of headwater wetlands requires the correct evaluation of their ecological and trophic state, which is connected to the detection and verification of appropriate biological and chemical indicators. Most investigations of wetlands emphasise the quality and

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composition of macrophyte communities and their relation to the water quality. Many investigations address the processes in the sediments and in the root zone of the macrophytes, especially in the context of natural wastewater treatment systems. However, there is also increasing interest in the planktonic communities of wetlands and their role in eutrophication processes. The aim of this study is to clarify the role of planktonic communities (phytoplankton and bacterioplankton) in eutrophication processes in landslide lakes using a broad range of routine indicators for estimation of trophic state.

2. Materials and Methods

2.1. SAMPLE COLLECTION

This study was carried out from May 2001 to September 2002. Water samples were collected at 0,2 m below the water surface from the pelagic zone of the lake (Kiselev,1956).

2.2. ABIOTIC PARAMETERS

Water temperature and oxygen content were measured with oxymeter - “OXI-196” and pH with “pH 323/set” field equipment manufactured by Wissenschaftlich-Technische Werkstetten (WTW). The chemical oxygen demand (COD) was measured by “WTW-mini test”(ISO 14 000). The biochemical oxygen demand (BOD1, BOD3, BOD5) was measured according to APHA (1982) (without sample pre-treatment). Total suspended solids (TSS) was determined by the ”dry weight technique” (APHA, 1982) and chlorophyll-a (chl-a) was measured spectrophotometrically (ISO10260).

Ammonia (NH4-N), nitrite (NO2-N), nitrate (NO3-N) and phosphate (PO4-P) were determined spectrophotometrically with laboratory kits (MERCK). The codes of the methods are: NH4-N method # 14752; NO3-N method # 14773; NO2-N method # 14776; PO4-P method # 14848 and total phosphorus (TP) - method # 14848 after digestion with per-sulfate and sulphuric acid at 120oC for two hours. Alkalinity was determined according to ISO 9963-1 by titration with 0.1 N HCI and brom-krezol green – methyl rot as an indicator.

2.3 BIOTIC PARAMETERS

Water samples for phytoplankton (0,5l) were fixed with lugol solution then gravity concentrated to 30ml final volume of the settled samples. The enumeration of the phytoplankton was carried in Burker chamber and the results presented in cells per cubic meter. The species were determined and enumerated with microscope (Amplival) at magnification x400. Total bacterial count (TBC) was determined by direct microscopic enumeration on membrane filter after staining with erythrosine [9]. Saprophytic bacteria (SB) were enumerated by indirect "plate count" technique according to the routine microbiological practices [8]. Saprophytic bacteria were cultivated on organic-enriched agar. Trophic indices were calculated by the method of Carlson [3].

3. Site description

The system of landslide lakes known as the Dragichevo wetlands is situated on the southern slopes of Ljulin Mountain between 870 and 950m.a.s.l. near Dragichevo village and 22 km away of Sofia. Dragichevo Lake is the biggest (Table 1) of thirteen wetlands, most of which dry up in the summer.

Parameter	Value
Maximum length	95m
Maximum width	38m
Maximum depth	3,1m
Mean depth	1.11m
Surface area	3 035m^2
Volume	3 045m^3

Table 1. Morphometrical parameters of Dragichevo lake.

This lake is divided into two sub basins with different morphometry: a northern with maximum depth of 3,1m and a southern with depth of 1,1m (Figure 1). The bottom sediments of the lake are also distinctly different in the sub basins. The shallower part of the lake is covered with a thick layer of organic sediments while, in the deeper part, the sediments are more dense and lack macrophyte debris.

Apart from the western bank and a small part of the eastern bank, the lake is surrounded by a belt of emergent vegetation – *Typha latifolia*. Approximately 80% of the lake surface is covered by dense submerged vegetation – *Potamogeton natans* mixed with two species of *Chara* and around the bank *Callitriche cophocarpa* with possibly some *Sparganium minimum*. The sub basins are divided by shallow waters, and at low water level a mud bank almost separates the basins. A patch of *Schoenoplektus lacustris* has recently started to overgrow the *Potamogeton* at that place (Figure 2), which is evidence of the rapid loss of depth.

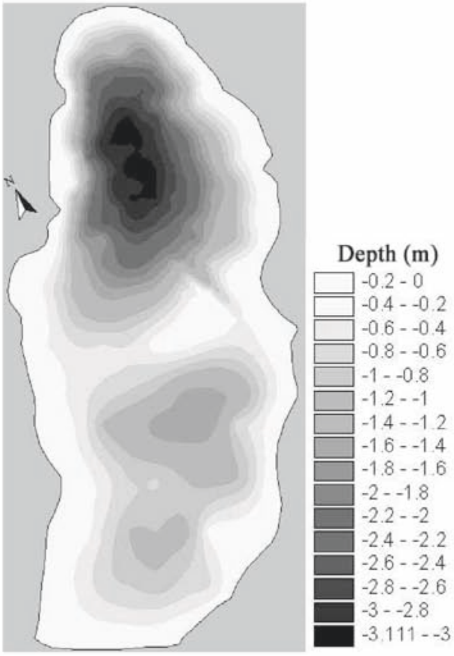

Figure 1.Bathomeric map of Dragichevo lake.

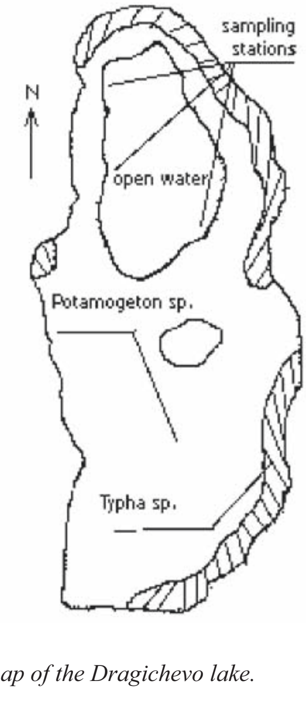

Figure 2. Schematic vegetation map of the Dragichevo lake.

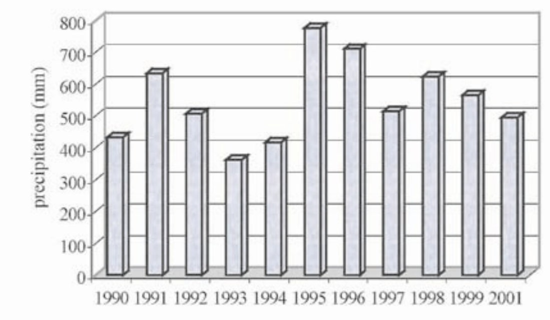

Figure 3. Annual precipitation.

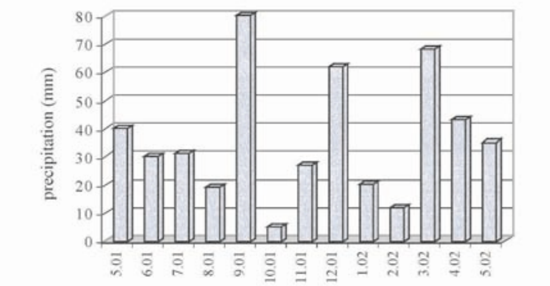

Figure 4. Monthly precipitation.

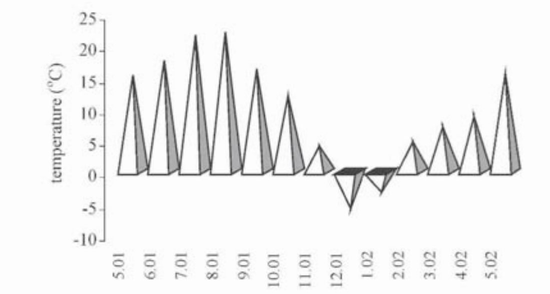

Figure 5. Mean-monthly air temperatures.

The landslide wetland system has small catchment - cca 100 ha, 70 ha of which are above Dragichevo Lake. The upper catchment is covered by cultivated forests of *Pinus nigra, Populus deltoides, Populus tremula* and remains of a natural forest of *Quercus pubescens*. The water level in the wetlands is regulated by surface runoff and groundwater supplies. Mean monthly (Figure 3) and annual (Figure 4) precipitation vary strongly. The annual amplitudes of air temperatures are high (Figure 5). This determines the large changes in the temperature and chemical parameters of the lake.

In periods of high precipitation and snow melt the ponds in the wetland system are connected by a temporary brook that transforms into a small river at the lower end of the cachment, then flows down to join the Strouma River.

In the past, drainage channels had been dug at the lower part of each wetland decreasing the water level in the individual wetlands by 30 to 50 cm to the detriment of the whole system. Due to the decreased water level, the area of the open water in the system has shrunk and most, apart from Dragichevo Lake, has been overgrown by macrophytes. This drying up threatens the existence of rare and endangered species as: *Chara, Emys orbicularis, Misgurnus fossilis, Salamandra salamandra, Triturus vulgaris, Hyla arborea.*

4. Chemical variables

4.1 TEMPERATURE

The average value and amplitude of the water temperature in 2001 was lower than the average water temperature for the corresponding period of 2002 (Figure 6). The high range of water temperatures in Dragichevo Lake is due to the strong water level fluctuations in the wetland. The lower water temperatures in 2001 are probably the cause of the low phytoplankton numbers in 2001, as well as the higher concentration of oxygen relative to 2002.

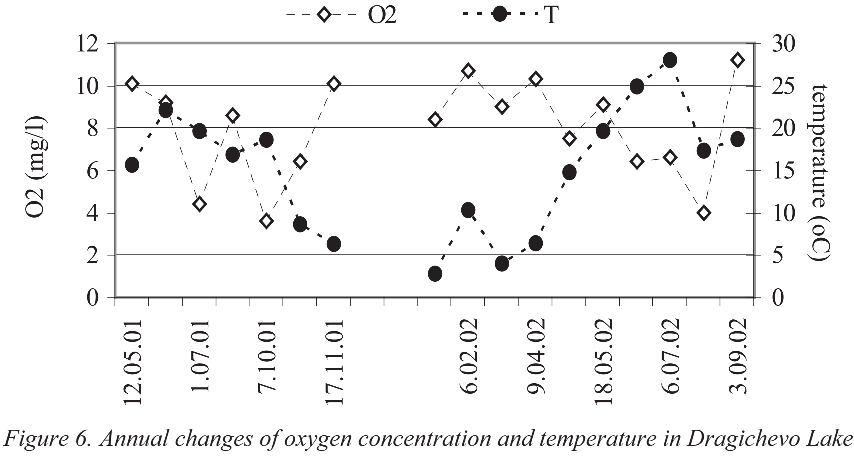

Figure 6. Annual changes of oxygen concentration and temperature in Dragichevo Lake.

4.2 OXYGEN

Comparing the May to September periods of the two years, the oxygen concentration in 2001 was 0,6 mg/l higher than the average for 2002 and the oxygen saturation greater by 10%..The annual amplitude of variation of oxygen content in Dragichevo Lake was high. The period with oxygen deficit was twice as long as the period of oxygen over- saturation, which indicates intensive respiration and biodegradation. So, changes in oxygen content were affected by the high amplitude of water temperature change, changes in the water level and variations in phytoplankton development.

4.3 NUTRIENTS

The annual changes of NH_4-N, NO_2-N and NO_3-N are presented on Figure 7. The concentrations of ammonium and nitrate nitrogen in the lake are almost twice as high (and those of phosphorus twice as low) as data from similar Bulgarian lakes [2]. The maximum values of NH_4-N measured in the autumn were 1,5 to 3 times higher than the average and in the summer of 2002 – 3 times the average. The peaks in NH_4-N concentration coincide with the periods of rapid decrease in oxygen concentration and increases in phytoplankton numbers. Minimum concentrations were measured in the spring of 2002.

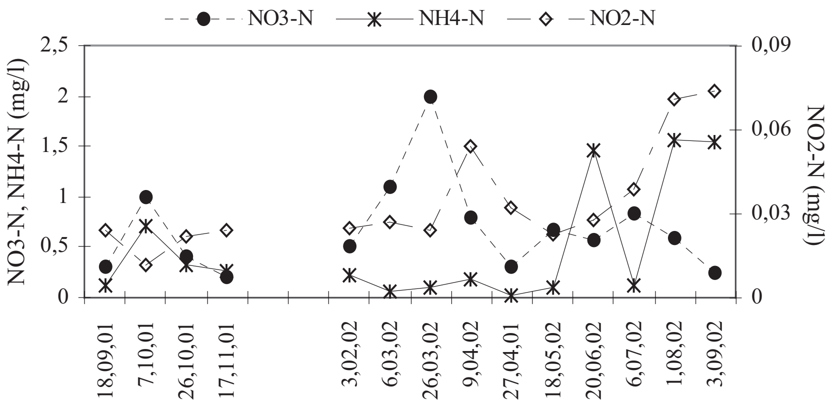

Figure 7. Annual changes of NH_4-N, NO_2-N and NO_3-N.

Maximum concentrations of NO_2-N coincide with the peaks of NH_4-N. In August and September 2003, concentrations of NO_2-N were twice the average. In the autumn of 2001, a peak of NO_3-N (1mg/l) as well as another one in March 2002 (1,1-2 mg/l) was observed (Figure 7).

The periods of low PO_4-P correspond with high values of chlorophyll-a concentration (5-254 ug/l) (Figure 8). It is possible that plankton rapidly recycle nutrients and thus sustain their development under low PO_4-P concentrations [16] or possibly, significant amounts of phosphorus in the lake weres incorporated into the biomass of the phytoplankton and/or bounded in metal complexes in the sediments [4,5,6].

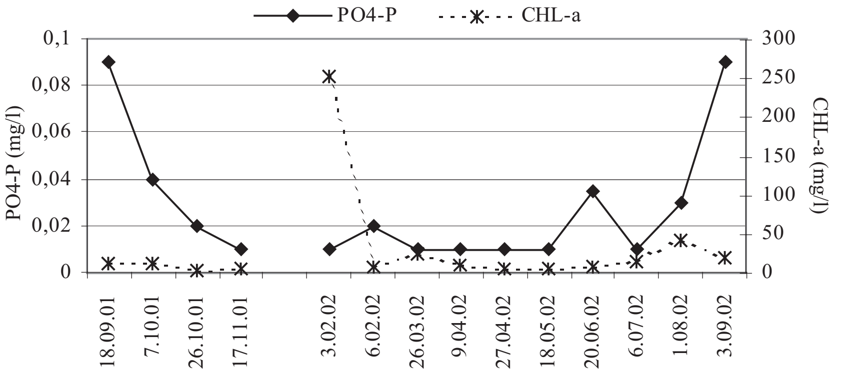

Figure 8. Dynamics of chl-a and PO4-P in Dragichevo Lake.

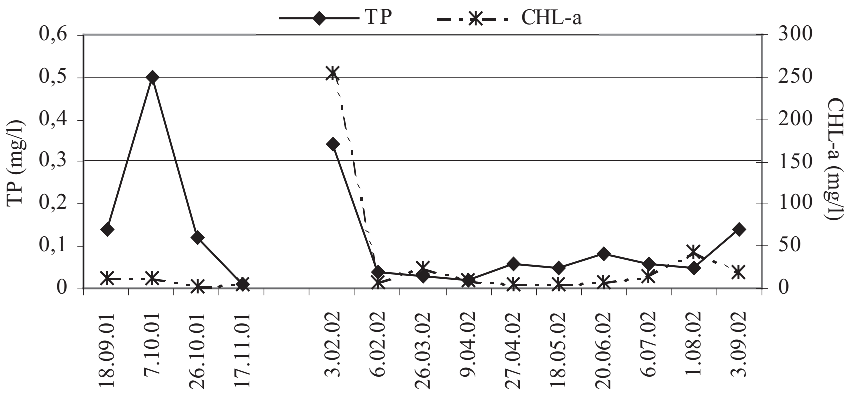

Figure 9. Dynamics of chl-a and TP in Dragichevo Lake.

Changes of TP and PO_4-P are similar - two peaks in the autumn periods and increased concentrations in July 2002. The highest value of TP was measured in October (0,5 mg/l). The autumn of 2001 is characterized also by high levels of total suspended solids (average 13,5 mg/l). Strong increases in TP were measured in February 2002 during the winter bloom of the phytoplankton. For the most part TP concentrations remained in the range 0,1-0,8 mg/l (Figure 9). By contrast, TSS data have complex dynamics and show additional peak in April 2002 (Figure 10).

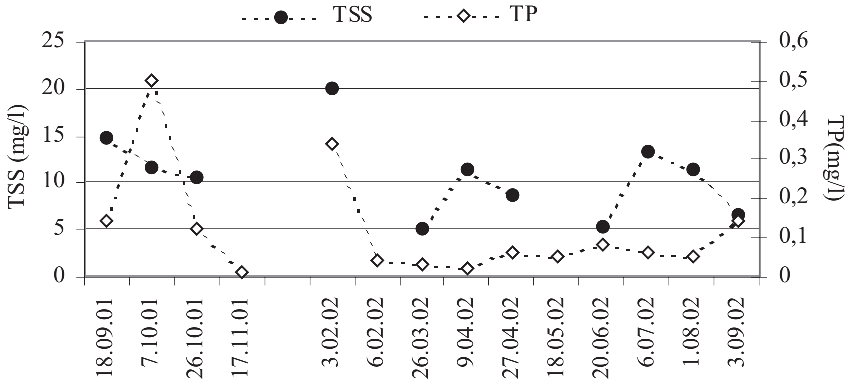

Figure 10. Changes in total suspended solids and total phosphorus concentrations throughout the investigated period.

4.4 pH

The pH of the lake waters is neutral to slightly alkaline and remained. almost constant (6,8 - 7,5) throughout the study period with only one exception in May 2002 (pH = 5). This was due, probably, to the high buffer capacity of the water (alkalinity of 2,8-4,0 mg/eqv).

4.5 BIOCHEMICAL AND CHEMICAL OXYGEN DEMANDS (BOD AND COD)

Changes in organic substances in the lake were studied through measurements of COD and BOD (BOD1, BOD3, and BOD 5. The values of COD were high throughout the investigation (average 200mg/l) and did not correlate with other measured parameters.

BOD5, BOD3, and BOD1 had parallel patterns of variation (Figure 11). Unusually, oxygen and BODx also changed in parallel (Figure 12). A correlation between BODx and chlorophyll-a concentration was also observed. Evidently, the phytoplankton possesses a strong influence on the values of BODx [14, 15], while COD was influenced by humic substances, which is typical for shallow lakes [16].

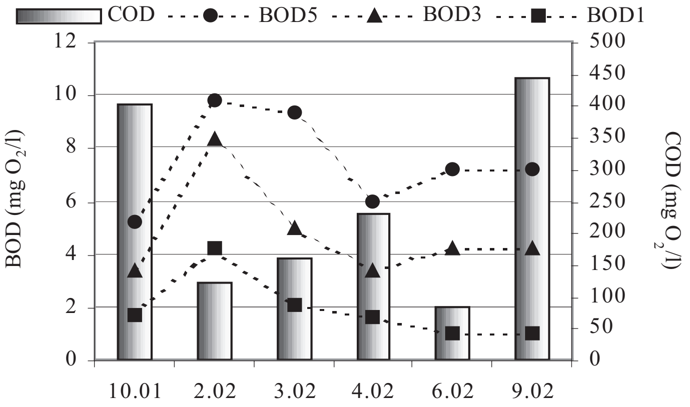

Figure 11. Dynamic of the COD and BOD1, BOD 2, BOD 3 in the lake.

5. Biological parameters

5.1 PHYTOPLANKTON

The Dragichevo Lake phytoplankton includes 83 species of 9 groups. Despite the high diversity of species (Table 2) and groups (Figure 13) compared to other Bulgarian wetlands [11], the group diversity of the phytoplankton is generally low. The highest diversity of groups is observed in July 2001 and September 2002.

Group		Number of species
Cyanophyta		7
Zygnemophyta		10
Cryptophyta		2
Bacillariophyta		18
Chlorophyta		24
Xantophyta		2
Euglenophyta		14
Dinophyta		6
Chrysophyta		2
Total	9	83

Table 2. List of phytoplankton species in Dragichevo Lake.

Cryptophyta were dominant in the lake from summer 2001 to April 2002 with two exceptions only, when Bacylariophyta were the most abundant.

In May 2001 Chlorophyta prevailed followed by Dinophyta, while in the same period of 2002 successive blooms of Dinophyta (May) and Chlorophyta (June) were observed.

There were extremely low quantities of Cyanophyta in 2001, while in 2002 two peaks in their numbers were observed. The Cyanophyta reached 24% in April and 21% in July mostly due to *Anabaena sp*. Presence of *Microcystis sp.* was not encountered throughout the investigated period. The success of the Cyanophyta is strongly dependent on the humic compounds in the waters and the circulation pattern of the system [10].

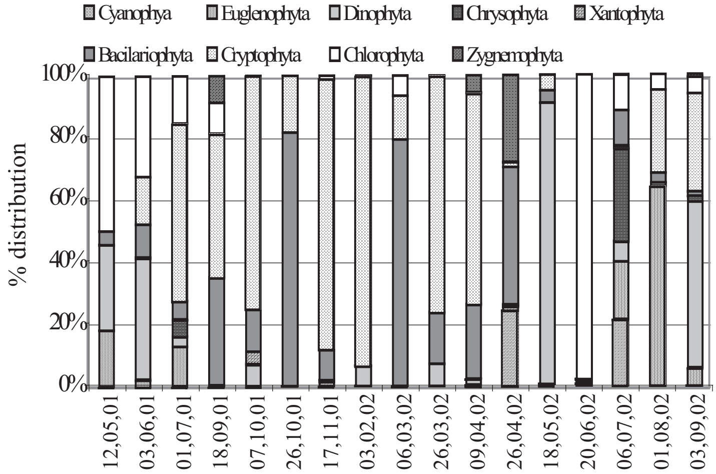

Figure 12. Distribution of the different phytoplankton groups in the samples.

Such seasonal variability in the different phytoplankton groups is typical for polymictic eutrophic lakes. The pattern is similar in both years but higher temperatures in 2002 allow the appearance of the prevailing groups one month earlier.

The numbers of the phytoplankton in the lake waters varied between 16,3x106 to 623x106 cells/m3 (Figure 13) with an average of 133,3x106 cells/m3. The number of phytoplankton in 2002 was 5 times higher than in 2001. The maximum was in June of both years.

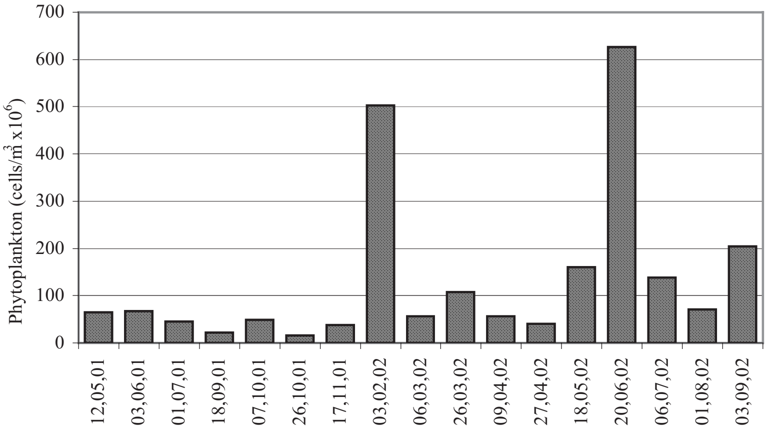

Figure 13. Changes of the phytoplankton cell numbers in the samples.

Differing from the phytoplankton numbers, the chlorophyll-a (chl-a) concentration in the second half of 2001 is slightly higher compared to the same period of 2002 (Figure 14). The average chl-a concentration in 2001 was 24 ug/l, while in 2002 it was 18 ug/l. The maximum measured chl-a concentration – 254 ug/l was during the winter bloom of Cryptomonas sp. in February 2002 and the minimum - 2.6 ug/l was measured in October 2001. The minimum and average chl-a concentrations for the whole 2002 are 5 ug/l and 39 ug/l, respectively.

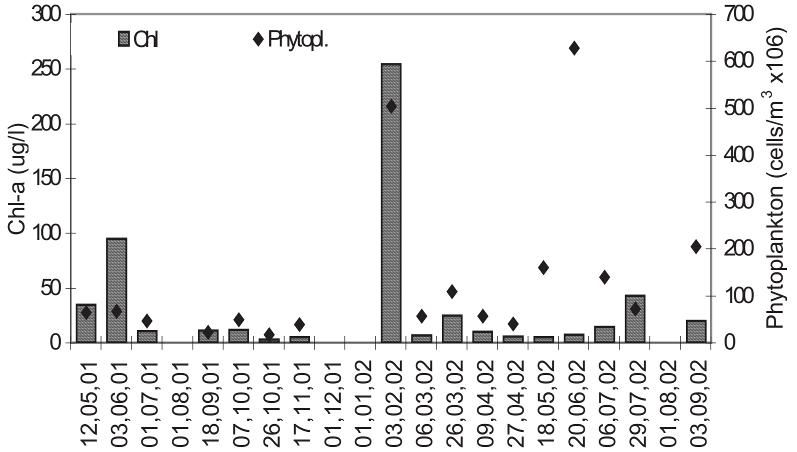

Figure 14. Quantity of chlorophyll-a and phytoplankton in Dragichevo lake.

Throughout the investigated period, chl-a concentration correlates significantly with numbers of phytoplankton (r2 = 0.89) (Figure 15). Such dependence was not observed from May to September 2002 (r2 = 0.27). In the summer of 2002, mass development of Dynophyta (*Dinobrion sp.* – 90%) and Chlorophyta (*Monoraphidium contortum* – 98%) led to the biggest discrepancies in the relationship.

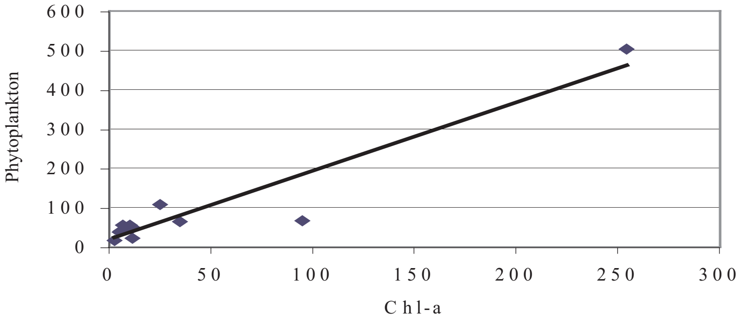

Figure 15. Correlation between phytoplankton and Chl-a, May 2001 – April 2002.

5.2 BACTERIOPLANKTON

In contrast to phytoplankton, the quantity of bacteria was low and relatively stable. The total bacterial count (TBC) varied between 40 – 200 x 103cells/ml, excepting a spike in October 2001 (1008x103 cells/ml) (Figure 16) when peaks in TP and COD were measured too. The quantity of saprophytic bacteria (SB) was also low and stable (1-4x103 cells/ml).

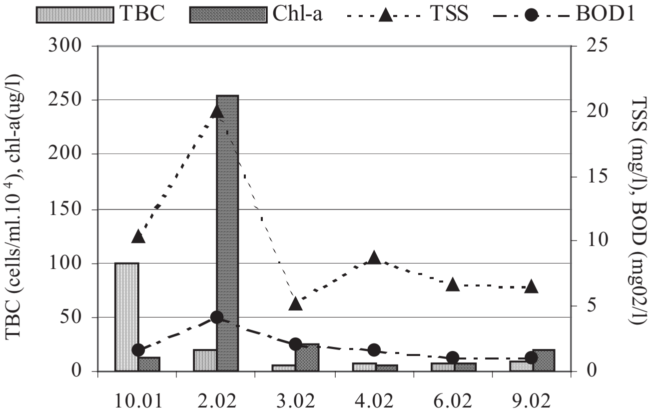

Figure 16. Changes in total bacterial count in relation to chlorophyll-a, total suspended solids and BOD1.

TBC showed relationship only with the suspended solids in the water (rs = 0,714) (Asenova et al., 2003) and did not depend on the concentration of organic substances measured as BODx and COD. Therefore, the quantity of bacteria was influenced more by resuspension than by the amount of available organic substances.

5.3 TROPHIC STATE INDICES

The average values of the Carlson's trophic state index derived on the basis of chl-a concentration (TSICHL) and total phosphorus (TSITP) are 56,8 and 64,2, respectively (Figure 17). These data suggest possible phosphorus limitation for the following months; November 2001, March – April and August 2002. Otherwise, the higher values of the TSITP could indicate that factors other than phosphorus limit the development of phytoplankton. In October 2001 the values of the TSITP are almost twice those of TSICHL, again due to the re-suspension of bottom sediments following a series of storm events with heavy rainfall. Increase in TSITP is also observed after the spring rains in 2002. The winter maximum of TSITP was entirely due to phytoplankon-incorporated phosphorus.

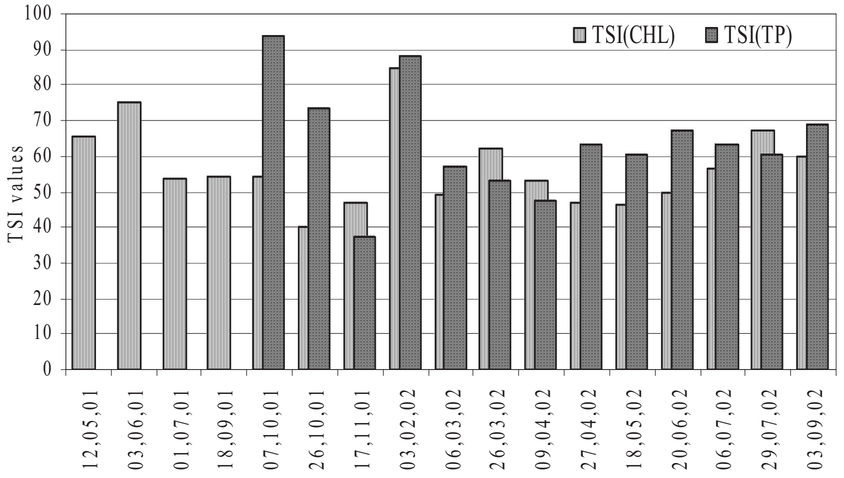

Figure 17. Carlson's trophic state indices calculated on the basis of chlorophyll-a concentration (TSICHL) and the amount of total phosphorus (TSITP).

6. Discussion

6.1 CHEMICAL PARAMETERS

The highly pronounced annual amplitude of the water temperature variations in Dragichevo Lake is due to strong water level fluctuations. These are determined by environmental factors and human activities in the catchment. Despite the polymictic nature of the lake, the periods with oxygen deficit prevailed over the periods with oversaturation, which indicates intensive respiration and biodegradation processes in the wetland.

The twice higher concentrations of ammonium and nitrate nitrogen in the lake are mostly due to the input of nitrogen as faecal material from the animals in the surroundings of the lake and from active decomposition. The low phosphorus concentrations, compared to data from similar Bulgarian lakes [2], are due to the absence of human settlements in the catchment. In the periods of ice cover during the winter peak of the phytoplankton, concentrations of NO_3-N, NO_2-N, NH_4-N and PO_4-P were below average because of their uptake in the phytoplankton. After the winter maximum of phytoplankton, the concentration of NO_3-N increases and those of NH_4-N remain low, indicating active nitrification during the spring. In the summer and autumn, concentrations of NO_3-N decreased. The opposite tendency was observed in NO_2-N. This was due to incomplete nitrification in the summer and/or active denitrification. Denitrification processes predominate in dense vegetation during late summer and early autumn. Uptake from the water column is active in the early summer during the rapid growth of the macrophytes.

During the March peak in NO_3-N concentration mass development of Dinophyta was observed. The summer peak of NH_4-N coincided with a peak in Chlorophyta. The autumn increase in NO_2-N concentrations corresponded with high levels of Zygnemophyta and Cryptophyta in the plankton. Of course, the nutrients influence the amount of the phytoplankton and vice versa.

The changes in the TP concentrations are similar to those of chl-a in 2002, while such connection was not observed in the autumn of 2001. The discrepancies in 2001 were due to heavy rains, which increase both TP and PO_4-P concentrations in the waters. In the absence of external forcing, the amount of TP in the water is mostly formed by phytoplankton. A substantial part of the readily available phosphorus in shallow lakes is found in sediments rather than in the water column. Therefore, the traditionally used “total-P” is far from being a perfect indicator for the nutrient status of shallow lakes. In shallow lakes, a considerable part of the available phosphorus is stored in the sediments and rapidly returns to the water column during resuspension [13].

Although, the free water surface in the lake is small compared to the macrophyte beds, the phytoplankton plays a significant role in the dynamics of nutrients in the water. It tends to increase the total concentration of nutrients in the water column, especially the concentration of phosphorus by two main mechanisms: high photosynthetic activity causes the pH in the water to rise and in this conditions the capacity of iron to bind phosphorus decreases; phytoplankton remove PO_4-P from the water column and stimulate the desorption of phosphorus from sediment and suspended particles. In the case of Dragichevo Lake, the second mechanism most probably prevails as the water in the lake is well buffered, pH is relatively stable, and the sediments except iron, contain also manganese and other metals in high concentrations [12].

The COD and BODx data show that considerable concentrations of organic substance exist in the wetland. COD and BODx did not correlate with parameters such as: TBC, quantity of saprophytic bacteria, and TSS. Even more, there is no correlation between both parameters for the investigated period, which should be present if we consider the fact that easily degradable organic substances increase the proportion of BOD in COD.

The high values of COD and the absence of correlation with all other parameters are linked to high amounts of humic substances in the water. BOD correlates with chl-a only and follows the changes in the oxygen concentration. Here, the BOD was influenced by the phytoplankton. It can be confirmed that in the Dragichevo Lake, COD and BODx do not reflect, correctly, the amount of autochthonous organic load in the wetland.

6.2 BIOLOGICAL PARAMETERS

Highly pronounced peaks of different phytoplankton groups with high deviations from the mean value, typical for shallow polymictic lakes, were observed in the Dragichevo Lake. Microcystis sp. was not found and there were no blooms of Cyanophyta in the lake. This supports the suggestion that the lake is not nitrogen limited, which in combination with the diverse environment and external forcing decreases the possibility of Cyanophyta blooms.

The high correlation between the quantity of the phytoplankton and chl-a concentration gives the possibility to use the relationship for estimation of the phytoplankton quantity, which would make the monitoring much easier and faster. In the wetland this correlation was disturbed by the development of certain phytoplankton species like Dinobrion sp. and Monoraphidium sp. In such systems the use of total chlorophyll concentrations as a monitoring tool could be more appropriate.

The quantity of bacteria in Dragichevo Lake is low for eutrophic water body and this parameter has significant positive correlation with TSS only. Positive correlation was observed between the growth rate of bacteria and organic substances too [1]. Therefor, the amount of organic substances influenced much more bacterial activity than bacterial count. Important limiting factor of the bacterial quantity is predation of zooplankton and reduction of resuspension by submersed macrophytes, but those relationships have not been studied in the lake yet.

The observed discrepancies between the trophic indices (TSITP and TSICHL) were entirely determined by external forcing, such as rain events and wind. The values of the indices in calm weather are close to the theoretical equilibrium and suggest that most of the total phosphorus is incorporated into the biomass of the phytoplankton. The TSICHL index is more suitable for determining the trophic state in small wetlands, as it reflects the actual amount of the phytoplankton and is not so strongly dependent from sporadic events in the catchment.

7. Conclusion

In a detailed study of a shallow landslide-dammed, the accent was put on the characteristics and role of planktonic communities. The results suggested that re-suspension processes (connected to rain events and wind action) influenced both the plankton communities and dynamics of chemical parameters significantly.

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NEW WETLAND FORMATION IN SUBSIDENCE HOLLOWS OF WESTERN DONDASS, UKRAINE

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KEYWORDS / ABSTRACT: Wetland formation / koloks/ mining subsidence / mine-water geochemistry, Western Donbass, Ukraine /

In the Ukrainian steppe zone, erosion processes expose shallow water tables creating wetlands in gully bottoms and river valley terraces. Here, small birch-aspen woods ("koloks") replace pine forests on sandy soils with high moisture. In the Western-Donbass coalfield, similar ecotopes form in artificial hollows caused by mining subsidence. Detailed examination of soil and hydrological characteristics demonstrate that, despite major differences in water qualities, these mining-subsidence induced "koloks" provide useful insights into the processes and evolution of their natural equivalents.

1. Introduction

The Steppe zone of Ukraine is situated in a continental-temperate climate area where moisture is the one of the main limiting factors and xerophilous grass associations dominate the natural vegetation [1]. However, in river valleys, pine forests form. Here, erosion processes may expose shallow water tables creating wetlands in gully and river valley bottoms. Some of the wetlands on steppe-river floodplain first-terraces are of special interest because they result from aeolian processes. In these depressions, small birch-aspen woods ("koloks") replace pine on wet sandy soils.

In the Western-Donbass coalfield of eastern Dniepropetrovsk, similar ecotopes form in artificial hollows caused by mining subsidence. The subsidence and flooding destroys both the natural and artificial pine

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forests and allows their replacement by typical-looking "koloks" dominated by birch (*Betula pendula* Roth.) and aspen (*Populus tremula* L.).

2. Evolution of 'Koloks'

The normal vegetation on the first terraces of river floodplains in the Samara Basin is pine forest, which forms on thick, loose residual sandy soils with a flushing regime and a prevalence of oxidizing processes. When ground water reach <3 m of the surface, the moisture activates reduction processes that starve the pine roots of oxygen. In the upper soil profile, litter decomposing processes intensify and organic matter content increases. When the subsoil waters table is <1.5 m, the soil regime can change from flushing to exudative. Oxidizing processes continue to take place in the upper soil horizons during the dry summer period but, during rainy periods or after snowmelt, the soil is flooded by temporary ponds. This flooding is the main cause of the replacement of the pine forests with the birch-aspen "koloks". Also under this regime, the topsoil changes to an eluvial-illuvial type with the eluvial layer often 30–40 cm thick. Below, the illuvial horizon contains much ferric oxide, hydroxide, and organic matter. In mine subsidence hollows, the situation is complicated by flooding with saline ground waters that have been pumped up to drain the deep coal mines.

3. Western Donbass Coalfield Subsidence Hollows

The Western Donbass is one of the most environmentally damaged regions of the Ukraine. Covering 12500 km^2, its coal seams, containing reserves of about 25 billion tons, run under the Samara Basin at depths of 200-700 m. Following mining, subsidence, equivalent to about 90% of the depth of the extracted layer, is common and large areas become flooded.

Mining involves the pumping away of ground waters that would otherwise flood these mines. These mine waters are loaded with heavy metal ions and salts, especially Na^+ and sulphides. They are pumped into storage ponds, where the pumped water should settle and be subjected to biological remediation. Unfortunately, at present, these processes are not up to standard and much mine water seeps away to mix with, often contaminate, but also to raise the levels of subsoil waters. Several strategies are in current use for the reclamation of these mine subsidence hollows. These include: the drainage of areas flooded to 2.0 – 2.5 m to encourage subsoil water level recession and soil de-salinisation, the creation ponds for deeper floodwater accumulations; and the infilling of such hollows with mine spoils, which is followed by their reclamation and revegetation.

4. Study Site and Methods

The study area is located near Sosnovka, Boguslav and Bogdanovka villages in Pavlograd, Dniepropetrovsk oblast. Species analysis has been undertaken on 10×10m test plots. Soil, waters and vegetation have been examined by standard methods [2, 3, 9]. Biodiversity has been assessed with the Shannon (α-biodiversity estimation) and Simpson (dominance estimation) indexes [5, 7, 8, 10]. The edaphic regime phytoindication has been assessed by means of the Tsyganov ecological scales [11].

5. Results

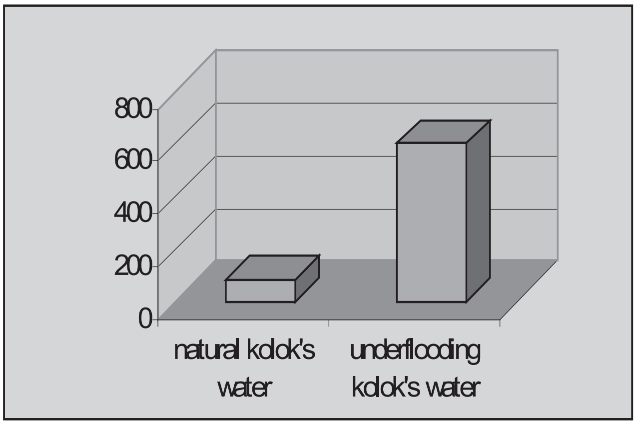

Figure 1. Comparison of the mineralisation of water in koloks, mg/1.

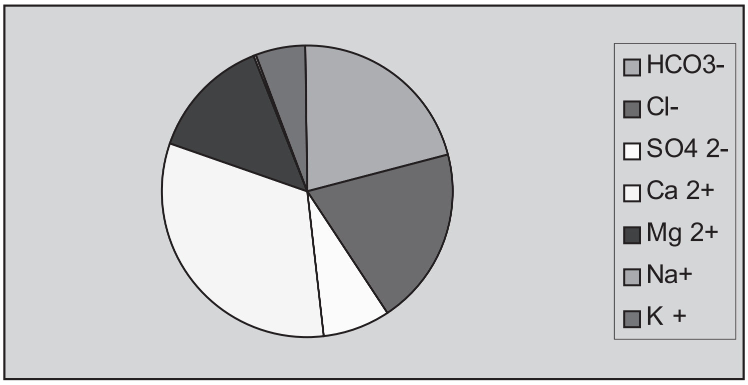

Figure 2. Composition of water in natural koloks.

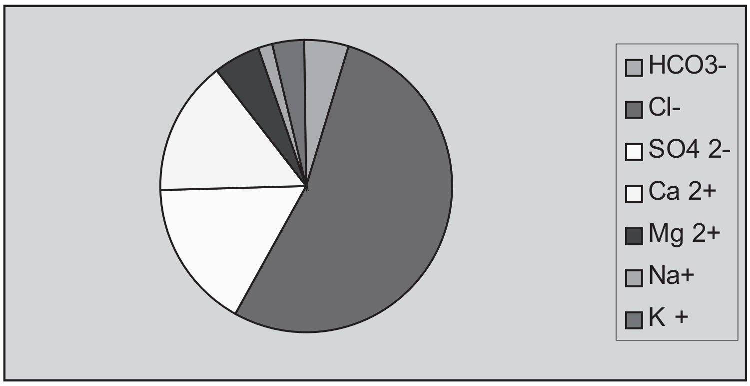

Figure 3. Composition of water in mine-subsidence koloks.

One major difference between natural and mine subsidence koloks is water quality. The mineralization of subsoil water is much smaller in natural native than anthropogenic koloks: 83 mg/l and 601.9 mg/l respectively (Figure 1). The anion and cation water composition of mine subsidence koloks has higher chloride (318,6 mg/l) than the native koloks (16,1 mg/l) and higher sulphate – 6 and 99,4 mg/l respectively (Figures 2 and 3). Ca^{++} ion content is greater 26.71 (natural koloks) and 90.8 mg/l (mine-subsidence koloks); similarly Mg^{++} -11.35 and 22.4 mg/l respectively. However, salinisation is not a problem. The Na^+ levels are low: 0.25 and 8.8 mg/l respectively. Differences in pH: – pH 7.7 and 6.7 respectively – may be explained by high levels of HCO_3^- in the water of the natural koloks.

Birch (*Betula pendula* Roth.) and aspen (*Populus tremula* L.) form the tree canopy of these ecosystems while the under layer is composed of by wetland species and water-resistant plants typical of the northern coniferous and deciduous forest zone. Many ruderal and meadow species occur in the ground layer herbage of the mining subsidence koloks.

The α-biodiversity index (Shannon index) is close to 1. The index of dominance (Simpson index) varies depending on the type of vegetation, i.e. it has both determinant associations with relatively high biodiversity and 3–4 dominant species, and associations with low biodiversity and a single absolute dominant species. The wide range of biodiversity indexes is typical for primary vegetation serial stages, where vacant niches and their active colonization characterize the habitat. The D.N. Tsyganov [11] scales for phyto-indicators of edaphic-factor regimes were determined for mine-subsidence koloks.

- The soil-humidity regime ranges from a bog-woody-meadow to a meadow-steppe type; the most prevalent regime is a humid-woody-meadow moistened by capillary backwater with subsoil waters at a depth of 1 – 2 m.
- The salt regime of the soils is ranges from a high level of salts (200 – 250 mg/l) to low salt levels (circa 95 mg/l).
- The acidity of the soils ranges from neutral (pH 7.0 – 7.5) to distinctly acid (pH 5.0 – 5.5). The variation is associated with water logging.
- The regime of soil nitrogen ranges from sufficient nitrogen (close to 0.4%) to very low in nitrogen (close to 0.2%). Low nitrogen soils (0.2 – 0.3 %) are typical for primary vegetation serial stages. Soils with sufficient nitrogen develop just above the ground-water level where there is intensive organic matter accumulation in the upper topsoil horizon.

	Soil moisture	Salinity	Acidity	Soil Nitrogen
Soil Moisture	1,00			
Soil Salinity	-0,56	1,00		
Acidity	0,06	0,47	1,00	
Soil nitrogen	-0,01	0,37	0,42	1,00

Table 1 Correlations between soil properties in mine-subsidence koloks.

Table 1 shows a significant negative correlation between the soil humidity and salts in these soils. Salts are removed from sandy topsoil's by washing and flooding. Significant positive correlations were found between the salt content of soils and pH, salt content and nitrogen level, and organic matter content and pH. These correlations reflect organic matter humification and decomposition processes caused by periodic flooding from groundwater overflow. The phyto-indicators correspond with chemical analyses of the soils and subsoil waters.

6. Conclusion

In general, examination of the birch-aspen small woods ("koloks") that form on mine-subsidence areas of the Western Donbass are useful for studying the processes involved in the formation of ecosystems on wetlands on the sandy first terraces of the flood-plain of Steppe rivers, despite the major differences between the water qualities of these and natural kolok wetlands..

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INTEGRATING WETLANDS INTO WATERSHED MANAGEMENT: EFFECTIVENESS OF CONSTRUCTED WETLANDS TO REDUCE IMPACTS FROM URBAN STORMWATER

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KEYWORDS / ABSTRACT: Constructed wetlands / integrated watershed management / flood control / water quality / dissolved metals

Water detention and water storage during storm events, and water release during dry periods, are some of the main functions wetlands can provide in order to help reduce peak flow and increase low flow runoff into streams. However, wetlands can also be effective in retaining and remediating contaminants. Results of the case study on a constructed wetland that mitigates urban storm-water are discussed. The effectiveness of metal reduction in water is highly variable and not all metals are detained and reduced at the same rate. Concentrations of certain metals in the sediments were not sufficiently reduced, which remains a challenge that can likely be resolved by improving the wetland design. A sediment detention pond could be constructed before the runoff enters the wetland and the sediments accumulated in this pond would then have to be removed and treated on a regular basis. As urban development continues to encroach on hills and sloping terrain, the use of wetlands to regulate water flow and retain contaminants will became more viable.

1. Introduction

Traditional urban development creates large areas of impervious surfaces which means a large proportion of the rainfall can no longer infiltrate and thus extensive storm-water conveyance systems are required [1]. This has a

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profound impact on stream hydrology and water quality [9]. Similarly, many forestry, agricultural and recreational activities compact the soil surface which in turn results in reduced infiltration rates, loss of water storage capacity and higher surface runoff that often results in increased erosion. The cumulative response of creating impervious surfaces and compacting soils results in a stream-flow regime that is more flashy, the risk of flooding in lowland areas is increased, and pollutants that accumulate on impervious surfaces enter streams more rapidly and effectively.

Traditional engineering approaches are usually relied upon to counteract the problems of higher and flashier runoff by diverting storm-water directly into streams and then modifying stream channels to remove floodwater more rapidly. The new paradigm for water management is to infiltrate and store as much rainwater as possible at the site level, while taking precautions not to overload the soils with water that creates instability. This includes the establishment of a permanent vegetative cover that is capable of intercepting and retaining water [25] and then releasing it more slowly into streams or undergoing evapotranspiration. The portion of the rainwater that is recycled via plants and soils and evapotranspired back into the atmosphere is usually referred to as green water [23] while the runoff water that enters streams, lakes and groundwater is usually referred to as blue water. We have lots of experience in managing blue water but have largely ignored managing the green water cycle. There is much to be gained in improving the management of green water and wetlands can play a key role in this process.

There is a long history of draining wetlands because landuse activities in and around wetlands are usually limited due to poor shear strength and aeration of the soils, which is not conducive for growing crops and trees. However, wetlands have many functions that are of great advantage to watershed management. Wetlands moderate stream-flow and can retain large quantities of storm-water. They tend to have high capacities for contaminant removal and carbon accumulation. Also, habitat for a wide range of organisms and unique vegetation communities is provided in the wetland environment, which contributes significantly to biodiversity. There is renewed pressure to protect wetlands in headwaters and widespread efforts are being made to restore formerly drained wetlands or to create new constructed wetlands because of the realization that wetlands provide many benefits. Draining wetlands is relatively easy but constructing wetlands that perform most of the desirable functions is much more challenging.

The aims of this paper are to review the key functions wetlands provide for watershed management, identify the positive and negative factors that influence the effectiveness of wetlands in moderating water quantity and quality, and to document, on the basis of a case study, how constructed wetlands can be used effectively for storm-water management on sloping terrain.

2. Key functions of wetlands in watershed management

Wetlands are considered both "the kidneys of the landscape", because of the functions they can perform in the hydrological and chemical cycles, and as "biological supermarkets" because of the extensive food webs and rich biodiversity they support.

Wetland conservation and rehabilitation is considered a cost-effective way to retain large quantities of rainfall within the watershed and to moderate stream-flow during storm events. Incorporating wetlands into watershed management plans is rapidly emerging as an innovative way of providing multiple functions which include flood control, stream-flow moderation, groundwater recharge, sediment detention, pollutant retention and phyto-remediation. However, a careful analysis of type of wetlands and site-specific conditions is necessary when quantifying wetland functions, and when proposing wetland creation or rehabilitation for particular environmental services.

Not all wetlands perform all of the hydrological functions to the same extent. Indeed, some wetlands perform hydrological functions which may be contrary to human needs, such as riparian wetlands which may act as runoff generating areas, thus increasing flood risk downstream [2], [7].

Headwater bogs are wetland systems that are sustained almost entirely by inputs from rainfall. A unique plant community consisting of a relatively small number of plant species survive in these low nutrient input systems. The productivity is low, the site conditions very acidic and the key functions of bogs in the watershed context are to retain large quantities of rainwater and to store carbon.

In contrast, fens, marshes and various types of swamps are wetlands that also retain large quantities of water but are flow through systems. This means that nutrient input is enriched because a portion of the water input has traveled over or through the soil system where it picks up nutrients. This leads towards a plant community that is more diverse and usually dominated by sedges, reeds, and shrubs [26]. Fens, marshes and swamps may therefore provide functions related to retention of nutrients, thus improving water quality downstream.

3. Wetlands and Water Balances

Moderating the impact of extreme rainfall events and providing base-flow during dry periods is one of the key functions of wetlands. This is a well documented function of wetlands and many constructed wetlands are now being incorporated in water sensitive planning and site designs [14], [3].

Both at the catchment and global scale, wetland drainage has meant a deterioration of the green water cycle. As wetlands are drained, less water is held in the catchment to be evaporated and transpired by wetland plants, and a larger portion of precipitation becomes blue water faster. This reduces the water storage capacity of soils (the land component of the hydrological cycle) and augments peak flows.

The reduction of water stored in catchments both in soils and wetlands (green water) constitutes a reduction of the biggest portion of the hydrological cycle that can be influenced by humans. The total amount of water that is held in soils is almost 40 times the amount of water that is available in rivers [4]. It becomes obvious, therefore, that wetland conservation has a vital role to play in alleviating the global ‘water crisis’, because wetlands are the places where that accessible and manageable water exists.

The amount of water that can be stored in wetlands is dependant on the site conditions (slope, size, geology and geomorphology) and organic matter content. Organic matter has very high water retention capacity and water storage is usually measured in terms of open water versus water contained in the saturated organic layer in the wetland [22]. The two most difficult components to determine in a wetland are groundwater losses and evapotranspiration. The former can be estimated from water table changes during dry periods by subtracting evapotranspiration rates [24]. Determining evapotranspiration is still a major challenge [25] and there is considerable debate whether evaporation from open water is greater than evapotranspired water from vegetated cover in the wetland. What is clear is that this is dependent on the type of plants, the community structure, and the plant biomass density. Measured evapotranspiration rates from a number of studies in wetlands range from 0.2 –19.9 mm/day depending on season, location and plant communities. Also, C3 plants are more water consumptive and less efficient water users than C4 plants but this is temperature dependent. Highly fluctuating water tables are also a factor that influences plant species distribution [21]. However, wetlands have much better water retention capacity than constructed ponds, and normal soil conditions.

As is the case in comparing watersheds, it is difficult to generalize what the key factors are that control the hydrological behaviour of wetlands. The site-specific nature of wetland processes, make quantification of the benefits of wetlands in regulating the hydrological cycle at any scale, a difficult task.

More conclusive results exist about the capacity of wetlands to reduce pollution impacts on receiving waters. This topic is of additional interest to storm-water managers because pollution from urban areas can be highly toxic and dynamic [19].

4. Effectiveness of wetlands for storm-water quality improvement

The use of constructed wetlands as wastewater treatment systems has become widely accepted in many parts of the world [5], [8], [27]. A combination of physical, chemical and biological processes contribute to the pollutant retention capacity of wetlands. In the past, wetlands have been used as treatment systems to deal with point sources of pollution but more recently they are proving to be effective in dealing with non-point sources of pollution from urban runoff.

Fine sediment retention is one of the most effective ways of retaining metals before they enter streams. Clay rich sediments have large negative charges and can therefore scavenge metals in storm-water runoff. The effectiveness of metal absorption to sediment is dependent on particle size, surface area, type of clay minerals, and prevailing water quality conditions. Organic matter also has highly negative charges depending on the state of decomposition and is also capable of adsorbing metals. The hydraulic residence time, and the extent of the plant cover largely control the efficiency of sediment detention [16]. Numerous studies have shown that metal retention in wetlands is highly variable but generally falls into the 25-50%

removal rates for metals such as Cr, Ni, Cu, Pb, and Zn [5], [20]. In contrast Fe and Mn are generally released from sediments in wetlands and the outflow water usually has significantly higher concentrations than the inflowing water [5], [6], [12]. However, this has not been observed in all studies and suggestions have been made that this might be dependent on Mn nodule formations and changes in pH, alkalinity and temperature. Fortunately these two metals are not considered to be the most toxic metals to aquatic organisms and plants.

Metals can be taken up by plants through bioaccumulation processes [28]. At low levels they can act as essential trace metals, but at high concentrations can become toxic. Plant tolerance to heavy metals varies widely. Some have blocking mechanisms while others sequester metals in compartments within the plant. Carbon content, pH, cation exchange capacity, and mineral constituents influence the rate and type of metals taken up by plants. Unfortunately few wetland plants are hyper-accumulators, although cattail and common reeds, which become dominant under nutrient enriched conditions, can tolerate heavy metals [17].

Some plants can take up metals through a process called phyto-remediation, but this process is relatively slow and requires that the plant biomass be removed from the wetland from time to time.

The uptake of excess nutrients by plants is another service provided by wetlands. This can have some very positive effects since it will reduce the eutrophication risk downstream. Storm-water runoff can contain significant levels of ammonia, nitrate and phosphate from garden activities, use of detergents and industrial processes. Nutrients are also retained in sediments and in the water column where they can be taken up by plants. Usually the nutrient uptake efficiency in wetland for TN, TP and ammonia and nitrate is in the order of 10-20%. Increased wetland size and water residence time can improve nutrient reduction significantly. Sedges, common reeds, cattail, and bulrush are some of the most effective wetland species to take up excess nutrients. Cattail is particularly useful as it is highly tolerant to fluctuating water tables within the wetland.

Pathogen removal in wetlands has been reported to range between 30% and 90% but is obviously less efficient during high flow events [5]. Other factors that have been suggested to influence removal efficiencies include types of plants, temperature, and suspended soils [15].

Retention of organic contaminants has also been reported. Some polycyclic aromatic hydrocarbons (PAHs) can accumulate in membranes of organisms and can affect negatively affect plants, as well as break down by light into photoproducts that can be more toxic. However, they do have a great affinity to be tied up in clay minerals. There is relatively little quantitative data available on the removal rates of PAHs and chemical breakdown, except that considerable amounts are tied up in clays. Also, microbial degradation is known to play a large role in the transformations of PAHs in aquatic ecosystems, which likely affects the removal efficiency in wetlands [11].

5. Long-term challenges in using wetlands for storm-water management

Input of excess nutrients will influence species composition, community structure and productivity. Most plant species adapted to low nutrient conditions do not respond well to high nutrient input and invasive species such as cattail and common reed, which are better adapted to these new conditions, will replace them over time.

Plants need metals in trace amounts but at high concentrations they can bioaccumulate and become toxic to plants. Plant tolerance to heavy metals varies widely. Carbon content, pH, cation exchange capacity, and mineral constituents influence the rate and type of metals taken up by plants. Since most of the wetland plants are not hyper-accumulators, the process of phyto-remediation is not a very effective long-term option particularly since it means that plants need to be harvested from the wetland from time to time and the amount of metals accumulated is relatively low.

One of the main challenges is how to deal with the first flush from urban storm-water runoff. When storms are preceded by a long dry period, the contaminants in the early part of the runoff are usually much more concentrated [18]. This can be dealt with by creating a separate detention pond that accommodates the first flush and the remaining storm-water is then directed into the wetland. This reduces the problem of continuously shocking the aquatic biota and plants in the wetland.

Sediment management remains a long-term challenge when using wetlands as storm-water treatment systems [13]. Sooner or later the accumulated sediments need to be removed and treated chemically. This is a relatively expensive proposition because many sediments originating from urban activities qualify as toxic contaminants and once removed from the wetlands they need to go through a special treatment process. Depending on the wetland type this only needs to be done on a decadal scale. Constructed wetlands are relatively easy to build and since they retain and remove a wide range of contaminants it is obvious that this approach is far more cost effective than trying to treat urban runoff water and sediments on a continuing basis downstream.

6. An example of a constructed wetland that mitigates urban storm-water: Oakalla Biofiltration System, Burnaby, B.C, Canada

6.1 SITE DESCRIPTION

The Oakalla Biofiltration System was constructed in 1990 to detain storm-water runoff from sloping terrain before it enters Deer Lake and to provide an aesthetic amenity to the surrounding park. A 0.3 km^2 primarily residential subdivision drains storm-water into the system. The system is composed of two ponds and one large marsh, creating a constructed wetland environment within the park. The surface area of the wetland system is 966 m^2 and has an approximate volume of 1615 m^3. Approximately 70% of the system is covered with cattails and grasses.

6.2. METHODS

A monitoring program was established in the wetland between July 2003 and June 2004 in order to investigate the quality of the storm water entering the system and the effectiveness of trace metal removal. Water sampling was done every three weeks at the inlet and outlet of each pond. Sediment samples from the top layer were taken manually at the inlet and outlet every three to six weeks. The U.S. EPA method for the determination of metals in environmental samples [10] was used to analyse the metals in the 63 μm sediment fraction. The technique of Diffusive Gradient in Thin Films (DGT) was employed to determine the accumulation of bio-available metals over time. The DGT units consist of a binding agent that accumulates solutes quantitatively after their passage through a well-defined diffusion layer. The DGT units were deployed for periods of three to four weeks at the inlet and outlet. After retrieval, the DGT units were analysed according to existing directions. Analysis for metal concentrations in the water, sediments and DGT units was performed on the Varian Simultaneous ICP-AES.

The results of the monitoring program were used to calculate the percent difference of measured parameters between the inlet and outlet using the following equation:

Percent Difference = ((Inlet Concentration – Outlet Concentration)/Inlet Concentration)*100

6.3. RESULTS AND DISCUSSION

The Oakalla Biofiltration System is effective in reducing all metals from inlet to outlet in both the wet and dry seasons. Results show median percent differences of 13% to 81% for dissolved metals in water, 20% to 81% for bio-available metals as measured by the DGT units, and 18% to 79% for total metals in sediments. These results reflect the variability of the system in its capacity to retain trace metals, which are affected by the season, inlet concentration and rates of runoff at time of sampling. The reductions in iron and manganese concentrations were high in the water, DGT and sediment, particularly in the wet season. The bio-available fraction was consistently reduced through the system for all detected metals, suggesting that the wetland has been effective in improving water quality for downstream aquatic habitat.

The consistent removal of contaminants is likely due to the metal binding capacity of the organic soils as well as the extensive vegetation. The cattails and grasses provide metal uptake, produce dissolved oxygen at the water sediment interface and reduce flows through the pond, which promotes settling of fine particles.

In contrast to the metal reduction in the water column, the overall reduction of metal concentrations in the sediments was not significant, despite some high percent differences between the inlet and outlet. The outlet concentrations of copper and zinc pose a concern, as 100% of samples exceed the Interim Sediment Quality Guideline of the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life (Cu: 35.7 mg/l; Zn: 123 mg/l) and 33 % of samples exceed the Probable Effects Level for zinc (315 mg/l). This suggests that despite successful contaminant reduction in dissolved and bioavailable metals, the wetland did not achieve all treatment goals. This implies that additional research is needed, with a focus on sediment retention and dynamics in the early portions of the system.

7. Conclusions

Wetlands provide many positive functions that need to be given more consideration as we intensify land use. Water detention and water storage during storm events, and water release during dry periods, are some of the main functions wetlands can provide in order to help reduce peak flow and increase low flow runoff into streams. However, wetlands can also be effective in retaining and remediating contaminants. In the present example it was shown that dissolved and bio-available metals in the water column were significantly reduced as the water moves through a constructed wetland. The effectiveness of metal reduction in water is highly variable and not all metals are detained and reduced at the same rate. Concentrations of certain metals in the sediments were not sufficiently reduced, which remains a challenge that can likely be resolved by improving the wetland design. A sediment detention pond could be constructed before the runoff enters the wetland and the sediments accumulated in this pond would then have to be removed and treated on a regular basis. As urban development continues to encroach on hills and sloping terrain, the use of wetlands to regulate water flow and retain contaminants will became more viable. What is needed is more research on how to make wetlands most effective in retaining and remediating contaminants that would otherwise enter streams and adversely affect aquatic biota.

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DISASTERS AND CLIMATE CHANGE - THEIR RELATION WITH WETLAND HEADWATERS

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KEYWORDS / ABSTRACT: Climate change / weather hazard / natural disasters / headwater wetlands

Headwaters are very vulnerable parts of natural ecosystems. Climate change in general creates an increase in natural disasters. Today, many hazards, such as snow avalanches or land slides, start in headwaters. Therefore, science should be engaged in the study of headwaters' sustainability, short and long-term weather forecasting (of precipitation, wind in particular), and the practical questions of how to prevent or diminish the influence of natural disasters in headwater environments In this paper, natural disasters, their causes, and observations of natural disasters in Slovenia will be discussed with special reference to prevention and prediction.

1. Introduction

Typical natural disasters in the middle latitudes of Europe are: floods of rivers, torrents, lakes and coastal areas; land slides and erosion caused by such floods in the Alps in particular; wind damage on buildings and forests; and sleet in forests and roads Most natural disasters are caused by the direct or indirect consequences of extreme weather events in areas with particular features of the earth surface. Mountain areas with steep slopes with headwaters in their upper parts are hit very often. Hazards are often observed in the regions where various climates meet, as well. So, in Slovenia, a small country with a rugged topography [9] on the sunny side of the Alps (20,000 km^2), where the Alpine, Pannonian, Mediterranean and Dinarical climates meet – many such disasters with large material

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losses – up to 2% of GNP - have occurred.

Several strategies are adopted to minimize the losses due to natural disasters in the country. First among these is to support the existing natural ecosystems and headwaters in particular, or to create new ones with the features of natural systems. In general, natural ecosystems are more resistant against natural disasters than man-made ones. Therefore, the latter must be adapted, as much as possible, to the natural state to minimize losses. The second strategy is a good system of disaster prediction combined with an effective warning system. The community must be informed as quickly as possible about the coming hazard to prepare the prevention measures needed.

This paper registers the various types of natural disasters observed in Slovenia, discusses the possibility of diminishing the losses caused and speculates about their frequency and strength in the future.

2. Natural disasters and their causes

There are many types of natural disasters but this paper focuses only on weather hazards, such as thunderstorms with their consequences like lightening strikes and fires, abundant precipitation, hail, floods and winds, wind related to conditions in the cold half of the year, spring frost and drought.

During the warm half of the year, most natural disasters are related to the static instability of the atmosphere, which can be illustrated with the following simple description. Static instability is defined as: "The condition of a body or system, which responds to a specified disturbance by increasing the disturbance until an irreversible change has taken place."[8]. Severe thunderstorms are caused by large instability of the atmosphere and launched by specific features of the topography [11]. They are observed during the warm half of the year. Their results are of various kinds: fires are caused by lightening strikes, abundant precipitation on the order of 300 – 400 mm per day are followed by local floods, wind damage, hail, etc.

The combination of the general circulation and cold air mass intrusions in particular, with specific features of the terrain, is responsible for strong winds in many areas of Europe [17] including Slovenia [12, 15]. Such winds are more frequent in the cold half of the year. The same combination – cold mass intrusion, specific topographic features like basins and valleys and clear weather - form conditions for the creation of spring frost [3].

The estimate of the frequency and severity of natural disasters in the future is one of the key questions concerning climate change. In general, natural disasters depend on the general circulation, topographic features of the region, and surface cover. The first and the last can be affected by climate change. The main cause will be the changed general circulation in connection with it the vertical stability of the atmosphere. On the basis of several publications mentioned by Houghton et al. [4], we can speculate that the frequency and the severity of weather hazards will increase in Slovenia in the future [6].

3. Observation of natural disasters in Slovenia

Slovenia has suffered many natural disasters. A chronicle of those during the XX century is given by Trontelj [19]. These events [9] have included thunderstorms [11], [16], floods [1], hail [5], winds [12], [14], and drought [6].

Slovenia, due to its location and topography, has the largest number of thunderstorms in Europe [11], [16]. The map of thunderstorm frequency – number of days with a thunderstorm - shows that a narrow belt of highest thunderstorm frequency extends from the Gulf of Trieste over the central Slovenian region towards the northeast and into Austria [10]. The map shows that the maximal values of 10-year averages of days with thunderstorms are close to 50 (Station Slovenjgradec 49), though in particular years the value may be close to 80 (Revenovše-Vojsko 77).

Due the general circulation over Slovenia, in the winter, frequent north easterly winds called bora affect the coastal region [12]. These winds [13], whether alone or combined with sleet or snow, cause many transportation disasters, either by preventing traffic or by causing overturns on tracks and line collisions. Also, in the interior of Slovenia in the region of Karavanke, strong winds due to general circulation are observed, causing a lot of damage to forests and buildings, taking away roofs, etc. [15].

During the cold half of the year, a combination of low air temperature at the ground, an anticyclonic situation and warm south-westerly flow at higher levels can lead to the occurrence of sleet. This causes much damage especially in headwaters. For example, a large natural disaster happened three years ago in a natural headwater in the Julian Alps close to the border with Italy. On 17 November 2000, after heavy rain, a landslide starting above 1600 m above m.s.l. took away 5 buildings and killed 7 people. The village has at present still not been restored.

3.1. CATASTROPHIC LANDSLIDE IN THE UPPER SOČA RIVER VALLEY LOG POD MANGARTOM' VILLAGE

A large landslide in the valley of the Mangart stream (named after Mangart Mountain, 1678 m.s.l.) occurred on Wednesday, 15th November 2000, at around 12:30–12:45. This landslide demolished around 150 m of the road Bovec-Predel (Italy), reached Predelica stream and stopped.

Some time later another and much bigger landslide started in the valley. The mass, which consisted of glacial morainic material, glacial lake sediments, fluvioglacial material, schists, sandstones, lacustrine carbonate silt and tuffs, ran into the bottom of the valley, Here, it became more and more saturated with water from the Mangart and other minor streams.

The critical point of water saturation was reached in the night of Thursday 16th when a big mudflow ran towards the village Log pod Mangartom (650 m.s.l). The mudflow demolished the bridge across the Predelica stream and covered, demolished or moved some buildings in the village. According to official data, seven people were killed. This landslide (mudflow) is rated the biggest natural disaster in Slovenia in some hundreds of years.

4. Prediction of natural disasters

Prediction of natural disasters is a very difficult task. In general, mathematical modelling can help. For weather hazards, we have to know the future characteristics of general circulation in the meso-scale for a particular landscapes and types of vegetation cover. These two factors define the conditions for the creation of weather disasters. A time scale, however, has to be defined and, often, there is a very short forecast period.

The severity of thunderstorms and the possibilities of their forecast have been intensively studied in Slovenia [2], [14], [19]. The one to two day forecast (with a lot of support from numerical forecasts of the circulation and atmospheric instability) is quite good at present, though their use in the forecast of local floods can be successful only with the combination with radar observation within a few-hour time period. Causes of floods in the coastal area are known [1].

Coastal flooding is caused by the combination of high tides, especially in winter months, low atmospheric pressure, and south-westerly winds. All three parameters can be predicted quite successfully - the first by astronomic data and the last two by weather prediction. Consequently, floods in the coastal areas are already predicted in the daily forecast.

5. Conclusions

To diminish the frequency and intensity of weather disasters and their influence on headwaters, the following should be taken into account: we can not influence general circulation of the atmosphere but we can modify circulation at meso- and micro-scales; the last is very much dependent on the land surface being afforested or bare.

Headwaters where the land surface is covered with mixed forests in Slovenia - should be preserved. In locations, where they will be anthropogenically modified or replaced, their characteristics should be very carefully studied in advance. It is important to make a smooth transition from the forest to the neighbouring ecosystem and avoid an abrupt change of the virtual upper border of the plant canopy. In this way, a large change of the surface boundary height, which can enhance turbulence, will not result. All types of construction – new settlements, roads, railways, factories, etc. - should be designed to promote and support smooth air movement over the landscape.

Some natural disasters can be predicted from other data and from immediate previous observations. Therefore, the causes of natural weather disasters should be carefully studied. On the basis of observations and models, good predictions can be made, but usually not very far in advance! A good warning system to alert the responsible services as well as the population is essential. Not all types of disasters or their severity can be predicted. Therefore the preparation of precautionary measures must be made in advance, and the community informed about them.

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THE ALLEGHE LAKE (DOLOMITES, ITALY): ENVIRONMENTAL ROLE AND SEDIMENT MANAGEMENT

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KEYWORDS / ABSTRACT: landslide-dammed lake / silting / sediment yield / sediment management / dredging

Landslide-dammed lakes in alpine valleys are often subject to intense silting due to the sediment transport of the tributary: sediment-related problems are thus of major importance in their environmental management. This paper describes the formation and evolution of an alpine landslide-dammed lake formed in 1771 (Alleghe Lake, Dolomites, Northern Italy) and also takes into account its significance to the economy of local communities. Since its formation, Alleghe Lake has been subjected to silting due to sediment transport of the tributary. Present problems regarding the Alleghe Lake arise from the need to remove and relocate deposited sediment in order to restore satisfactory environmental conditions. Sediment removal operations carried out over recent years are described and prospects for future management programmes are briefly outlined.

1. Introduction

Natural lakes are a valuable element of Alpine landscapes and are often used, along with artificial reservoirs, for electrical power production. Landslide-dammed lakes, formed due to the blockage of a drainage system by a landslide accumulation, are sometimes present in alpine valley floors. Sediment transported by the river dammed by the landslide accumulation and by other tributaries causes lake silting, resulting in the degradation of environmental characteristics. The filling rate mainly depends on the sediment yield of upslope drainage basins and on the size and shape of the lake, being higher for small lakes with a relatively large

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upslope area. The management of these lakes, aimed at maintaining or restoring their environmental and economic value, mainly deals with sediment-related problems.

This paper describes the historic evolution of a landslide-dammed lake in the Dolomites (Eastern Italian Alps) and its influence on local communities, and analyses the measures taken to deal with present problems caused by silting and the degradation of environmental characteristics. A more comprehensive analysis, regarding also the effectiveness of dredging operations and their impact on environmental conditions of the lake, will be carried out in a future study.

2. Study area: lake formation and evolution

Figure 1. Location map.

The Alleghe Lake (Dolomites, Northern Italy, Figure 1) formed on January 11th, 1771. A large rock failure from the right flank of the valley dammed the Cordevole River about one km downstream of the hamlet of Alleghe leading to the formation of the lake. Dam volume and height are $20 \cdot 10^6$ m^3 and 80 m respectively [5].

The drainage basin upstream of Alleghe Lake covers an area of 248 km^2. The basin is characterised by rugged morphology, indicated also by the wide range in elevation (from 968 to 3342 m) and high average slope steepness (60%). Geological conditions of the basin are rather complex: dolomites make up the highest mountain summits, whereas on most of the basin slopes conglomerates, tuffs, marls, thin layers of limestone and sandstone outcrop. Quaternary deposits, consisting of scree, moraines and alluvial deposits are widespread in the basin. Climatic conditions are typically alpine with cold winters and mild summers; average annual precipitation is about 1100 mm, with maxima in summer (July) and in autumn (November); snowfall is frequent in winter. With regard to land use, coniferous forests and pastures cover about 40% and 30% of the basin area, respectively. Vast bare areas (rocks and scree), mostly located in the upper parts of the slopes, cover about 20% of the basin. Shrubs, agricultural areas (mostly grasslands), and urban areas occupy the remaining part of the basin.

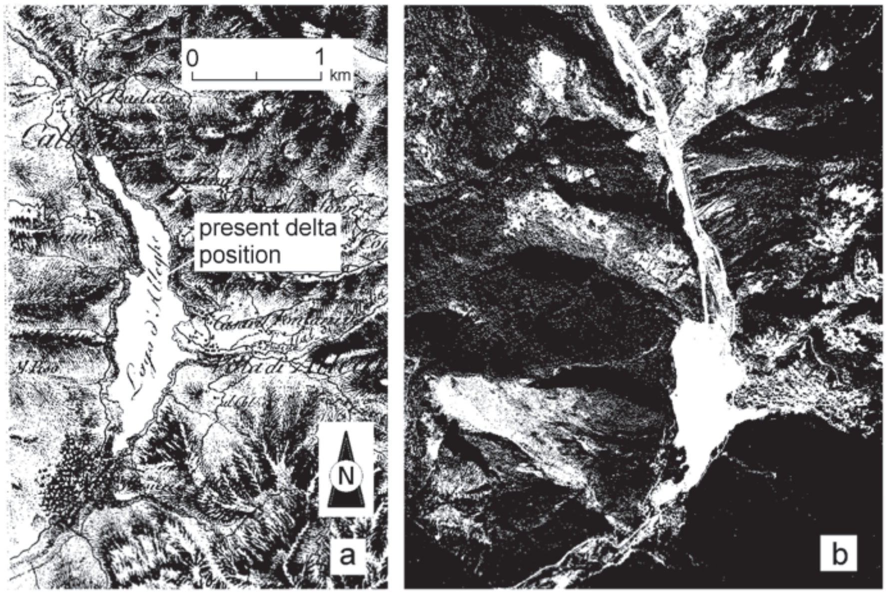

Figure 2. Alleghe Lake in the Austrian map of 1801-1805 (a) and in an aerial photograph of 1999 (b).

Both the Cordevole River and the landslide were the agents for the lake's formation, the river also being responsible for its filling because of intense sediment transport. Historical maps and field evidence indicate that the northern edge of the lake originally extended well upstream of its present position (Figure 2): today, Alleghe Lake is only a small remnant of what formed in 1771. Maps and drawings document the initial evolution of Alleghe Lake; some measurements of water depth and lake volume are also available from the late 18th and early 19th centuries. Since 1887, several bathimetric surveys [e.g. 8; 7] have recorded variations in lake volume and depth (Figure 3). Serious uncertainties affect early observations; differences in surveying techniques also influence more systematic measurements carried out since the late 19th century. In spite of the approximations in field measurements, the time series of lake depth and volume clearly displays how sediment deposition is leading to the filling of Alleghe Lake.

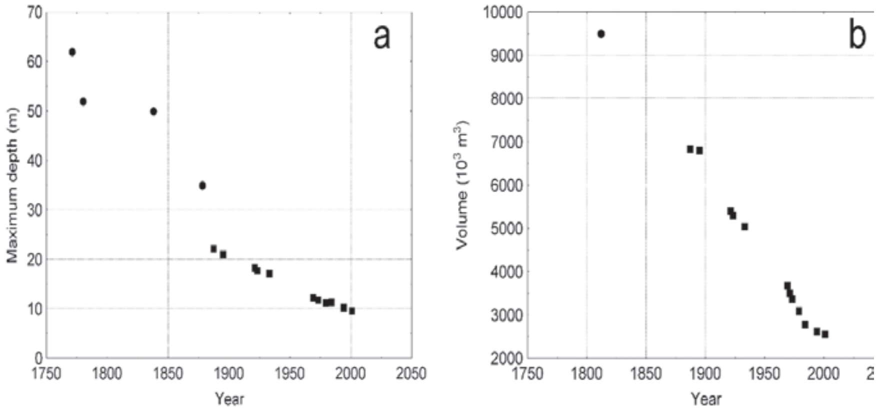

Figure 3. Decrease in maximum depth (a) and lake volume (b) over time. Different symbols are used for early measurements (circles) and systematic survey carried out since late 19th century (squares).

Long-term average sedimentation in Alleghe Lake (1933-2001), estimated from bathimetric surveys, amounts to about 37000 m^3y^{-1}, corresponding to a sediment yield of the upslope basin of 150 $m^3km^{-2}y^{-1}$. This value is consistent with other drainage basins in the Eastern Italian Alps. The sediment yield from 1933 to 2001 includes the contribution of large floods, such as the one that occurred in November 1966. Although infrequent, high intensity floods significantly affect long-term average sedimentation rates. Decidedly lower values were observed over recent years (about 10000 m^3y^{-1} from 1994 to 2001, and 16000 m^3y^{-1} from 1984 to 1994): this should be due to the absence of major floods in the last two decades.

Environmental conditions of Alleghe Lake are monitored by the Province of Belluno [1]. Figure 4 shows the concentration of chlorophyll and Secchi disc transparency measured from 1994 to 2002. The Secchi disc depth was also computed using the following relation [6]:

$$SDT = 9.33\ Chl^{-0.51} \tag{1}$$

where: *SDT* is Secchi disc transparency (m) and *Chl* the concentration of chlorophyll (mg m^{-3}). Measured transparency values are generally lower than those computed on the basis of chlorophyll concentration (Figure 4).

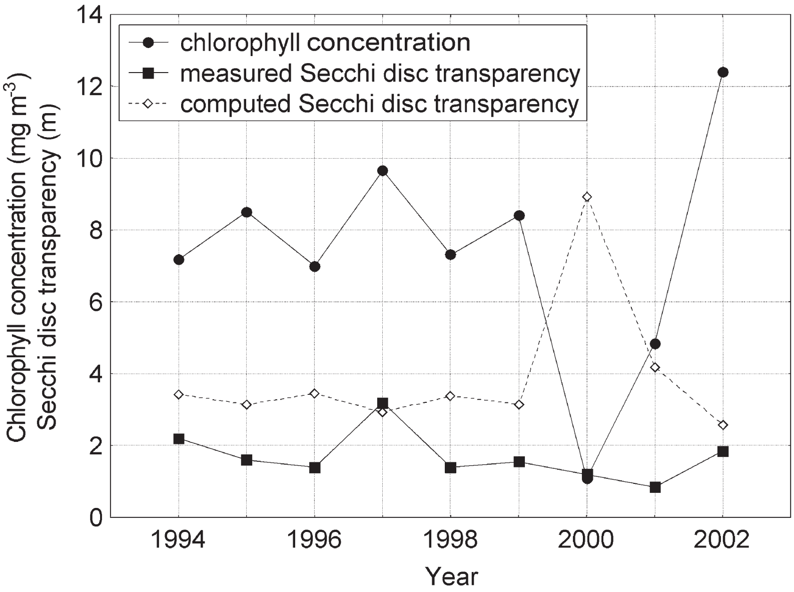

Figure 4. Secchi disc transparency and chlorophyll concentration.

Poor inverse correlation between the two variables is particularly apparent in the 2000 and 2001 data: minima in chlorophyll concentration correspond to low values of measured transparency. Low values of transparency are due to the presence of suspended inorganic particles transported by the tributary. Fluctuations observed in the chlorophyll concentration are ascribed to variations in water temperature and to the influence of water diversion on the development of algal populations [1].

The lake displays a rather weak thermal stratification. Gradients measured in 2001 and 2002 range from 0.44 to 0.53 °C m^{-1} in the centre of the lake and from 0.81 to 0.89 °C m^{-1} in its distal part. Temperature conditions are influenced by abundant water inflow from the tributary, low water depth and disturbance produced by water diversion for power production.

3. Social and economic influence of the lake

Since its formation, Alleghe Lake has seriously influenced the life and development of local communities. An immediate impact of the lake's formation is related to landslide activity. The landslide of January 1771 and the subsequent impoundment of the Cordevole River affected hamlets in the valley floor, which were rebuilt on a new site above lake level [3]. A second, smaller failure (May 1771), which fell into the newly formed lake, caused a flood wave which produced further destruction and loss of lives in the villages.

A negative, permanent effect of the lake's presence was the loss of agricultural areas. In the Cordevole Valley, as in many alpine areas, land suitable for agriculture is mostly located in valley floors: the lake's formation meant the loss of such areas. As agriculture, forestry and cattle-breeding were the only economic resources for local communities at the time of the lake's formation, this had a serious impact on economic conditions, which was balanced only in part by fishing in the lake. A further negative effect of the lake's presence, although less serious than the loss of agricultural land, consisted of making communication between villages in the Cordevole Valley more difficult.

Since the early decades of the 20th century, Alleghe Lake has become a resource, both for tourism, as it heightens the scenic value of the valley, and for the production of electrical power. In 1938, Alleghe Lake was involved in the plans for the exploitation of water resources of the Eastern Italian Alps for power production. A spillway for the regulation of water level stage was installed at the outlet of the lake, and a conduit was built to divert water to a power station. The fluctuations of the lake stage associated with the operation for power production conflict with its aesthetic value for tourism: the policy of lake operations adopted in recent years takes this problem into account by limiting water level fluctuations in summer months. In recent decades, the village of Alleghe, like many other areas in the Dolomites, experienced an important development of tourist activities. The presence of the lake contributes to agreeable scenery, increasing the popularity of the site with tourists.

However, over the most recent years, the silting of the lake is endangering its aesthetic value. Negative effects include delta progradation, low water depths in several parts of the lake and poor transparency (Figures 5 and 6). Moreover, sedimentation means a reduction in the lake's potential for power production because of the loss of storage capacity.

Figure 5. Gravel-sandy deposits showing delta progradation into Alleghe Lake.

Figure 6. Sediment deposition results in low water depth in various parts of the lake.

4. Sediment management and environmental problems

This loss of potential and the degradation of environmental quality urge interventions to remove sediment from the lake. For these interventions, problems, concerning both the choice of suitable techniques for sediment removal and the relocation of excavated sediment, need addressing.

Sediment discharged by the Cordevole River to Alleghe Lake displays a wide range of particle size: heterogeneous deposits, ranging from silt to coarse gravel are present in delta deposits, whereas finer fractions (silt and clay) prevail in the distal parts of the lake. Physico-chemical analyses indicate that lake sediments are non-polluted. The particle size of the deposits and the presence of material deriving from different lithologies, including rocks of poor mechanical characteristics, make the sediment of Alleghe Lake of limited suitability for use in road or levee construction.

A programme for managing the accumulated sediment and restoring the environmental conditions of Alleghe Lake has been devised and is being implemented by the power company Enel [4]. Two methods have been used in recent years for removing sediment from Alleghe Lake: sediment excavation by means of diggers and sediment dredging. In autumn 1999, after the lowering of the water level, sediment was dug from three sediment deposition areas. An initial project had considered the flocculation and thickening of fine sediment and its storage in areas outside the channel. This procedure was discarded because of high costs, possible pollution due to the use of flocculants and the difficulty of finding suitable storage areas in the narrow valley of the Cordevole River. Sediment removed from the lake was thus transported downstream of the spillway and redistributed in the channel by means of water jets. This technique allowed the excavation of a moderate amount of material (6000 m^3 in five weeks of operation) but required the waste of a large quantity of water, because of the need to keep the lake level low.

A more substantial sediment removal operation was carried out in 2003. Sediment dredging was carried out from September 8th to October 31st (after the end of the summer tourist season): a volume of about 40,000 m^3 of fine material was dredged and pumped to the penstock pipe which connects Alleghe Lake to a power station close to the downstream Ghirlo reservoir (Figure 7).

The Ghirlo reservoir is located in the Cordevole Valley about 8 km downstream of Alleghe Lake; the elevation difference between the two reservoirs is 217 m. No relevant damage was caused to the penstock pipe and the turbine blades by the passage of solid material. The use of the penstock pipe made it possible to transfer dredged sediment downstream without affecting the water quality in the channel stretch between Alleghe Lake and the Ghirlo reservoir. Sediment management in the Ghirlo reservoir is much easier than in the Alleghe lake, both because of the lower environmental value of the former and its smaller size. A further downstream transfer of dredged sediment will be carried out through the power plants in the lower part of the Cordevole River basin (Figure 7). Final retrieval to the channel of water-sediment mixture will take place in the lower part of the river system, avoiding environmental damage to most of the Cordevole River.

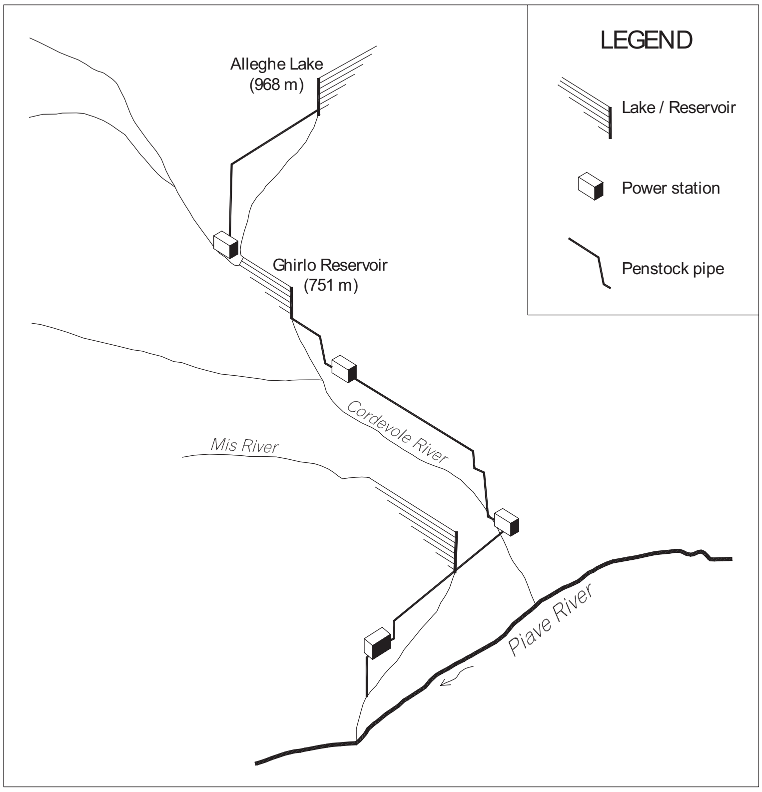

Figure 7. The path for downstream transfer of sediment dredged from Alleghe Lake.

The monitoring of the physical, chemical and biological parameters of Alleghe Lake will make it possible to analyse the influence of sediment dredging on water quality and trophic conditions of the lake. The use of penstock pipes for conveying the sediment dredged from Alleghe Lake is intended to minimise the impact of sediment management on downstream channel stretches. However, partial release of fine sediment could occur (e.g. from the Ghirlo reservoir or due to the retrieval of water from the power stations): a special monitoring program has been designed for assessing the impact of possible sediment release to the channel on fishery habitat [2]. Hydraulic dredging, which basically consists of sediment removal from the bottom of the lake using a strong suction pump, is being taken into consideration for future dredging programmes. In order to reduce damage to the benthos, suction can be applied to sediment layers lying below the bottom of the lake. Hydraulic dredging would be combined, like the mechanical dredging carried out in 2003, with the use of the penstock pipe for transferring fine sediment downstream. Hydraulic dredging is more environmentally friendly than mechanical dredging: this is of particular importance when operating in natural lakes of high environmental value. Possible problems regard the cost of the machinery and a longer time of operation in comparison to mechanical dredging.

5. Concluding Remarks

The Alleghe Lake is a good case to study the natural evolution of a landslide-dammed lake formed in historical time and its relations with the development of the economic context of an alpine community. Landslide-dammed lakes fill naturally due to sediment deposition, unless, as often occurs in alpine valleys, erosion and/or failure of the landslide dam cause their premature destruction. The filling of Alleghe Lake should then be considered the natural outcome of sediment deposition processes active since the lake's formation in 1771. Programmes for sediment removal can postpone this process, but it is not easy to envisage it can be avoided. Reducing sediment influx from the upstream basin to control lake silting is not a feasible option: torrent control works have already been implemented over recent decades, especially after the large flood of November 1966. Present sediment yield of the upper Cordevole River basin is in agreement with climatic, lithological, geomorphological and land use conditions and it would be hardly possible to reduce it further.

Sediment management in Alleghe Lake responds to strong social pressure for interventions aimed at restoring the positive environmental characteristics of the location. The approach implemented in 2003, which consists of dredging combined with the use of penstock pipes for transferring dredged sediment downstream, seems to provide quite encouraging results. The costs are decidedly lower than those required for transferring lake sediments to a waste disposal area. With regard to the effectiveness of long-term sediment management programmes, the comparison of basin sediment yield with the amount of sediment removed in 1999 and 2003 indicates that repeated sediment excavation and dredging can cope with lake sedimentation in “normal” hydrological conditions, such as those observed over recent years (annual deposition of about 10000 – 15000 m^3), but would probably fail to manage huge amounts of sediment discharged during major floods. Large floods in alpine basins are commonly associated with widespread erosion and instability phenomena, which dramatically increase the amount of sediment available for transport even when comparatively minor floods occur. The influence of large floods on sediment dynamics and lake silting is thus not limited to the flood event, but continues some years afterwards, causing further problems for the environmental management of the lake.

The environmental management of Alleghe Lake faces a difficult challenge: sediment removal is necessary for both electrical power production and for restoring the aesthetic value of the tourist location of Alleghe, but both the removal and the relocation of sediment pose considerable problems. Some management problems are common to other reservoirs: in particular, in alpine valleys it is not easy to find suitable places for the relocation of dredged sediment, and discharging fine sediment is harmful for water quality and fishery habitats in downstream channel stretches. A further problem of landslide-dammed lakes is the lack of a bottom outlet, which makes sediment management more difficult than in most artificial reservoirs. A possible alternative to discharging sediment downstream could consist of the transfer of dredged sediment to parts of the lake already affected by active sedimentation (e.g. the delta at the inflow of the Cordevole River). These areas would be chosen as “sacrificial” areas where sediment dredged from the lake would be stored. This approach accepts lake filling as the natural evolution of this type of water body, but aims at separating the lake, where sufficient water depth contributes to good water quality and scenic landscape, from sediment storage areas permanently above lake level, in which natural sedimentation is accelerated by the artificial transfer of dredged sediment. Geotechnical studies should be carried out and proper measures devised to avoid possible instability of semi-artificial slopes in these areas. Complementary works, e.g. re-vegetation with trees and grass, should be carried out to improve their environmental value.

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ALPINE WETLANDS FROM ECOLOGICAL NETWORK TO LAND-BASED RISK PREVENTION:

The Case Of Pian Di Spagna (Italy)

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KEYWORDS / ABSTRACT: *Alpine wetlands / risk management / ecological network / relict rural landscape*

The Pian di Spagna wetland remained a flood prone area until 1858, when the Adda River was canalized into Como Lake forming the new separated Mezzola Lake. Its ecological value was recognized in the framework of the Ramsar Convention, leading to the approval of a natural reserve conservation plan in 1996. The protected area covers 1586 hectares, including Mezzola Lake, which is affected by critical concentrations of chromium. Still, little attention has been paid to the protection of the Valtellina region based on wetland rehabilitation and policies for flood prone area recovery. Ecological networks, focused on the prevention of natural hazards, are a key issue in the context of Alpine valleys. In response to the increasing local vulnerability to upland 'renaturation' processes, multi-sectoral strategies are to be targeted to land use planning, in addition to enhancing coordination among land based protection measures.

1. A new approach to Alpine regions

The Italian wetland of Pian di Spagna is situated in the lowland crossing of the Valchiavenna and Valtellina valleys, where once the Mera and Adda rivers joined together on the northern side of Como Lake. Though it lies at a strategic position, along the historic paths connecting Swiss regions through the Splugen Pass, Valbregaglia and upland Valtellina, the area has always maintained a marginal profile, its flood prone area characteristics preserved in order to prevent military attacks from the

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Northern Alpine countries.

The two valleys' past social and economic conditions were similar to other Alpine regions; under-development in a vulnerable environmental context. Throughout the centuries, this condition led to a symbolic 'mountain profile', now formally established by both national and regional legal frameworks. However, this classification of 'mountain area' produces several contradictions, considering targeted policies, strategic priorities and incentives or funding schemes, when facing the relatively recent dynamics undermining its traditional, symbolic profile and belonging to a more complex 'Alpine transition': consolidation of local industrial districts, down-valley rural-urbanisation processes, and development of upland ski district and tourism activities.

Nowadays, statistics record well-founded economic development, rather than the former declining trends, and display an economic structure shifting from industry to provision of services. Today, both income levels and employment rates are higher than the related regional means.

Still, the wider territorial context of extreme vulnerability remains in the association of lowland flood hazards with upland landslides and debris flow risks. In this context, the need for a consistent and effective response to the risk prevention is addressed in an innovative land-based model of Alpine region management.

2. Migration background *versus* present trends

Pian di Spagna (the "Spanish Plain") is so called because, during the Spanish military occupation of the 17th century, it was part of the defence against Swiss attacks from the Ticino region nearby. As already mentioned, the area was connected to the Rhine and Swiss valleys, across the Splugen Pass and Valbregaglia, but the main basis of income remained related to pasture and forestry or locally, wine production. At the end of 1800, both valleys were affected by overpopulation. Between 1880 and 1890, 21,000 people left the area permanently, increasing to 84,000 between 1900 and 1915. By the time the First World War halted this emigration, migration had taken 14% of the Province's population. At this time, seasonal migrants, once moving according to livestock needs, became permanent residents by settling the lowland, or in new reclaimed land.

The first emigration cycle from 1870-1920 depended on wider rural trends, especially on the mid-1800s *Phylloxera* wine grape pest, rather than declining commercial exchanges across the Splugen Pass after the establishment of the Gottard connection, which became important later. Since the local infrastructure, focused on railways and hydropower plants, was not sufficient to counter migration in the short term, diminishing land use reflected the impacts of seasonal and permanent migration.

New structural, management solutions were established by the introduction in 1923 of the so called "hydrological constraint". Decree 3267 prevented any woodland and land use transformations resulting in damage to soil stability or increase in local landslide and flood risks. Although these constraints were not developed as an active risk prevention tool, after the Second World War they protected wider ‘renaturation’ processes within upland or less accessible areas, where human pressures on woodland were diminishing spontaneously.

Today. over 176,000 people live in the Sondrio Province, also following an increasing demographic trend, as opposed to the relative stability of the regular urban population. Although employment rates are falling in industrial sectors, they are increasing in commerce and tertiary services sectors. Land use patterns are typical of such rural-urbanisation: from a total of 78 municipalities, 72 have less than 5000 inhabitants, 30 less than 1000, with a mean density of 55 inhab/km2.

3. The "Gray Zones" of Rural Landscape Dynamics

Area (hectares)	**1990**	**1997**	**2000**	**2003**
1. Total rural area	**221.000**	**132.700**	**186.500**	
1.1 Unproductive fields border		5.700		
1.2 Other land	25.800	60.000	16.000	45.000 *
1.3 Unproductive land	20.700		31.700	
1.4 Woodland	78.200		46.500	
1.5 Productive rural area	**96.000**	**67.000**	**92.300**	
1.5.1 Permanent pasture	90.900	62.000	88.350	62.000
2. Unproductive area		**92.000**		
3. Other forests		**95.800**		**95.800**
TOTAL AREA	*321.200*	*321.200*	*321.200*	*321.200*
* poor pasture				

Table 1. Comparing rural statistics.

Concerning the rural context, last general census, held by the Central Institute of Statistics in 2000, shows some crucial data for understanding the influences of agricultural dynamics on evolving landscape patterns. According to current EU statistics, only farms basing their income on agricultural/forestry sector are monitored. Ten years after the previous census (when all farms were monitored), the number of farms has decreased from 15,500 to 7,500. Total rural area has fallen from 221,000 hectares to 186,000 but the productive area has declined only from 96,000 to 92,300 hectares. These few data, shadowing the tricky question of abandoned rural land, show the relevancy of changes in land use in mountain watersheds. Though there are "gray zones" statistics, a few comments should be made.

In 1997 within a productive rural area of 67,000 hectares, permanent pasture covered 62,000 hectares. Over 60,000 hectares were classified simply as "other land", and 5,700 hectares as unproductive field borders, leading to a total rural area of 132,700 hectares. Further unproductive land covered 92,000 hectares and woodland 95,800, equivalent to the total Province area of approximately 321,000 hectares. The 2000 Census reported 88,350 hectares of permanent pasture within a productive rural area of 92,300 hectares, and within the total rural area, 46,500 hectares of productive woodland and 47,800 hectares of "other land". In 2003, "poor pasture" covered 45,000 hectares, and forest 95,800.

Some figures show what could be called a high "migrating vocation" across statistics of non-permanently productive areas. The difference between total and productive rural area in 2000 is the same as the unproductive area in 1997. The sum of unproductive and other land, monitored in 1990 and 2000, is equivalent to the 2003 poor pasture area. By summing the difference between 1990 and 2000 woodland with the difference between 2000 and 1997 productive area, the result is equivalent to 1997 "other land".

In any case, the amount of permanent pasture and poor pasture (see unproductive and other land) has stayed about the same throughout the last ten years' statistical surveys: compared with a total extent of 321,000 ha, these areas cover 40% of the Province, and over 70% if combined with forested land cover.

There land cover change is large. Frequently, these changes affect the land’s hydrological functions: rural landscape "gray zones" varying from productive pasture to permanent set-asides, spontaneous ‘renaturation’ processes succeeding productive woodland, natural forest colonizing former poor quality pasture.

4. The Environmental Issues of a Vulnerable Landscape

The Pian di Spagna wetland formed on the Adda River by sediment transport processes, and remained a flood prone area until the Austrian dominated government started land reclamation in 1845. In 1858, the Mera and Adda deltas were divided and the Adda River was canalized directly into Como Lake, in order to initiate drainage.

The ecological value of the Pian di Spagna wetland was recognized in 1971 in the framework of the Ramsar Convention, leading to the institution of the natural reserve in 1983. The wetland management plan was approved in 1996 by the Lombardia Region. Today, the reserve is co-managed by three Mountain Councils (*Comunita' Montane*): Morbegno, Alto Lario Occidentale and Valchiavenna, which provide a volunteer body of ecologic wardens. Information services and training activities are supported by local environmentalist associations, which have established a Permanent Observatory in Novate Mezzola. The protected area is the biggest natural reserve of Lombardia, covering 1,586.42 hectares, including 493 hectares of the relict Mezzola Lake, reed (*Phragmites*) and sedge (*Carex*) beds, rare cat-tails (*Typha*) and grass land. Due to its geographical position, the area represents an important resting station on bird migration routes across the Alpine region. Around 200 nesting and migrating species have been monitored, as well as 24 aquatic bird species.

The Mezzola lake is affected by critical concentrations of chromium, loaded during the Seventies (and probably still being loaded) from the toxic waste discharge of the former Falck steel mill, close to the lake shore. The discharge reclamation plan, approved in 2001, has not yet been achieved. Nevertheless, because of the territorial dimension of the whole ecosystem, the main human pressures faced today are mostly related to the previously mentioned land use transformations around the wetland itself:

- Quarrying at Novate Mezzola (i.e. San Fedelino granite)
- industrial and commercial district expansion in the nearby municipality of Colico
- the new paved road towards Valcodera
- construction of small minor hydropower in secondary valleys
- canoeing and rafting recreation along the Mera River.

Even if the impacts may not directly affect the wetland quality, indirect effects on the water regime are to be expected in the medium term from the wider ‘artificialisation’ of the Mera river basin and from the fragmentation of the Valcodera catchment vegetation cover. As in the

Valtellina watershed, this kind of intervention involves severe and often non-reversible modifications of the hydrological regime, leading to increasing flood frequencies and peak flows.

Floods and landslides are a constant threat in Valtellina and Valchiavenna; extreme floods occurred in 1300, 1387 and 1502,. More recent floods and debris flow events include 1807, 1900, 1983 and 1987.

Between 1918 and 1990, 130 landslides were recorded, and 35 floods affecting the Adda catchment, 8 floods the Mera River, plus 7 minor river basins. In 1963, the extent of potential landslide risks was estimated in 378 hectares, affecting directly 20 settlements. In 1986 26 municipalities were assessed under natural hazards and in 1990, all the municipalities were listed as within high, or very high, risk areas.

The first multipurpose funding program was established only after the 1987 events: the so called "Valtellina law" n.102/90. It establishes, among other things, non-building zones along the watercourse, EIA procedures for major interventions, and the re-assessment of hydropower licenses. At that time, 10% of funding had to be assigned to land based solutions, such as bioengineering, headwater management, channels impact mitigation.

However, during the first ten years of application, most financial resources were spent for "emergency" rehabilitation works (1,5 billion Euros) and for river embankments (0,7 billion Euros). A hard engineering hydraulic approach has dominated the whole strategy of intervention.

To prevent supposed depopulation trends, medium slope settlements have been expanded, connected and served, increasing vegetation cover fragmentation and the need for river network ‘artificialisation’ within the upper areas. Soft prevention measures, such as forest and land cover incentive schemes, have yet to be promoted. In November 2002, after one week of severe rain storms, over 2000 people were evacuated, and there were two victims of minor debris flow events.

In 2001, the Po River Basin Authority defined new constraints for flood prone areas, within a risk map that will remain under discussion till April 2004. At that time constraints will be firmly established, obliging municipalities to respect risk perimeters in their own urban planning strategies. Still, deeper attention needs be paid to more comprehensive risk management planning.

5. Alpine Watersheds: topics for the future

The Pian di Spagna wetland is the core of a valuable ecological system, involving the National Park of Stelvio and the previously protected areas of the Orobie Mountains, Valcodera, and Adamello glacier. Moreover, the southern part of the Adda River (from Como Lake to the Po River) is already recognised as a protected area. Landscape quality protection measures are in place for the whole Como Lake area.

Among the 167 Lombardia sites of the Nature 2000 Network, most are situated in the Alpine side of the region. If the hydrological buffering function potential of these areas, which are located both upland and upstream, appears very high, it could be achieved only in the perspective of ecological networks that are established in the wider framework of European environmental protection policies and goals.

In the general context of Alpine regions, however, local settlement vulnerability remains very high, compared to ongoing 'renaturation' processes. So, there is also a strong need to promote ecological networks, in order to confront increasingly frequent risks of floods and landslides. This involves by shifting emphasis from purely environmental purposes to multisectoral functions recognising hazard prevention and mitigation.

Traditional Valtellina land cover can be seen as a multifunctional landscape, drawn through different levels from the Adda riverbed to the top of the mountains: the alluvial flood-prone area, a first zone of wine grape production from 500 to 700 m, a higher level devoted to annual crop production near to historical settlements, the upper traditional "rural food reserve" of chestnut wood, and the protective forest at the top.

Today, land consumption figures, associated with medium slope rur-urbanisation and upland ski district development, have widely modified natural hydromorphological factors, and they are inducing a spreading artificialisation that severely changes the run-off absorption capacity of the vegetation cover. Slope profile transformation and fragmentation (i.e. for new paved roads, ski structures) directly affect the stability of a vulnerable area that is naturally prone to short run-off times, higher water energy and large volume sediment transport.

Moreover, environmentally speaking, current rural often provide weak results in terms of soil protection. Even if spontaneous 'renaturation' processes can be consolidated, depending on local land use and cover conditions through set-aside pasture and woodland. This set-aside land is remains more likely to undergo subsequent development than remains permanent.

6. Conclusion

Multifunctional strategies of risk prevention, land use planning must enhance environmental measures of passive protection. A deeper coordination of land use targeted planning tools has to be established. In order to achieve effective environmental protection and hazard management, a new landscape management perspective is needed, both targeted to active risk areas affected by landslides and floods and to provide for other environmental concerns such as landscape and nature conservation. Watershed management and risk mitigation policies need to be based on an integrated land use planning approach (i.e. addressing land based criteria for biodiversity dynamic consolidation, sustainable forestry and set-aside practices, headwater and wetland protection, and for river divagation area rehabilitation along the watercourse).

The foreseen, general transition of rural landscapes, within the European enlargement process, fosters cross-compliance and decoupling incentive schemes of the European Community Agricultural Policy, as well as Watershed Integrated Management strategies in the framework of the Water Directive 00/60 expected implementation. Due to the high rates of employment in the Alpine region, the emigration of young people is an increasingly troubling issue: multifunctional risk prevention policies may also represent an occasion to offer new job prospects with higher social meaning.

7. Acknowledgement

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HEADWATER RESOURCES AND HEADWATER HAZARDS*:* PERSPECTIVES FROM ENVIRONMENTAL EDUCATION

Case Study Galtür, Austria

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KEYWORDS / ABSTRACT: Galtür / Alps / geography / environmental education / sustainability / global change / headwater area / mountain region

The environmental education concept developed for the village of Galtür, Austria, places emphasis on sustainability, global change and geography. With the dualism of headwater as both a resource and a hazard being of highest public interest and relevance in the Alps, 'headwater' is one of the core themes of the concept. In a case study, it is shown how this theme can be implemented in environmental education programmes, which focus on the sustainable development of mountain regions. Ways of transferring the concept to other headwater areas are discussed.

1. Introduction

Global change needs to be regarded as one of *the* high-priority issues of society, as its effects permeate all spheres of life and have a considerable impact on everyone. Global change encompasses not only climatic or ecological changes of the environment, but also economic, social and political ones as well as their interdependencies. Mountain headwater regions are especially susceptible to all aspects of global change and experience its effects first hand. Due to the high altitudinal gradients of these regions, meteorological, hydrological and ecological phenomena are diverse and very sensitive, and therefore, changes can be detected at an

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early stage [1, 2]. Moreover, land use possibilities are often extremely limited in space and type, which renders the population more vulnerable to these changes. Since the human impact itself increases often more rapidly than in lowland areas, mountain headwater regions are at higher risk of being affected by natural hazards [3].

Agenda 21 engages itself with the issues of global change and appeals for a sustainable development in ecological, economic and social terms [4]. High mountain regions, always headwater areas due to their topography, are given credit in several chapters of the Agenda. Chapter 13, *Managing Fragile Ecosystems: Sustainable Mountain Development*, is explicitly devoted to mountain regions and includes two programme areas. These recommend improving the knowledge about mountain ecosystems and their sustainable development as well as encouraging integrated watershed development and alternative means of subsistence [4,5,6]. Addressing the management, protection and use of freshwater resources, Chapter 18 is highly important for mountain regions, as these serve as water towers. By formally recognising headwater environments directly as well as indirectly, Agenda 21 calls clearly for their sustainable use and management and for providing the public with knowledge about headwater- and mountain-related global change issues. Additionally, the programme areas of chapter 36 of the Agenda comprise reorienting education towards sustainable development, increasing public awareness and promoting training [4].

Thus, environmental education in mountain headwater regions is to be considered essential, as the public needs to be provided with knowledge about the local environment and global change issues in general, in order to be able to contribute to a sustainable future of mountain ecosystems. Moreover, skills enabling the individual to act in a sustainable manner have to be taught, and the associated attitudes and values ought to be achieved implicitly. Chapter 20 of the *Nairobi "Headwater" Declaration for the International Year of Freshwater 2003* supports this perspective by declaring that "Greater attention should be paid to applied environmental education aimed at building capacity for headwater management and changing social attitudes against wasteful and polluting uses of headwater resources" [7].

The importance of environmental education was reconfirmed at the 2002 *World Summit on Sustainable Development* in Johannesburg. Following the recommendations of the World Summit, the 'United Nations Decade of Education for Sustainable Development 2005-2014' was adopted [8]. This decision marks an important step forward in strengthening the role of environmental education on a supranational level. However, it will remain in the responsibility of communities and regions to respond to this call for action and find appropriate ways of implementing the vision of sustainability at an operational (i.e. regional or local) level.

In the following, an example of an environmental education concept for an Alpine community in a headwater area will be introduced. With the respective village, Galtür in the Tyrol, permanently experiencing the dualism of headwater as a resource and a hazard, the theme 'headwater' is a core topic of the concept. A case study will show how this theme can be implemented in environmental education programmes, which focus on the sustainable development of headwater regions in the Alps. In addition, ways of transferring the concept of Galtür to other headwater areas will be discussed. To start with, insight into the state of the art of environmental education will be given as background information.

2. A Short Overview of the State of the Art of Environmental Education

Environmental education has its origins in the eighteenth century and has undergone significant changes as well as trends since then. Among others, Rousseau and Humboldt influenced environmental thought strongly, followed by reform pedagogues like Montessori, Hahn and Dewey [see e.g. 9,10]. From the late nineteenth century onward, various movements (e.g. Alpine Clubs, Nature Study Movement) lead to a new perception of and responsibility for nature. Several events and initiatives at an international level can be regarded as landmarks in the development of environmental education. At the *UNESCO Biosphere Conference* in 1968, environmental education made its official international debut [9]. In 1970, a joint *UNESCO/IUCN International Working Meeting on Environmental Education in the School Curriculum* originated the ‘classic’ definition of environmental education [IUCN 1970, in 11, p.28]:

> “Environmental education is the process of recognising values and clarifying concepts in order to develop skills and attitudes necessary to understand and appreciate the inter-relatedness among man, his culture, his biological surroundings. Environmental education also entails practice in decision-making and self-formulation of a code of behaviour about issues concerning environmental quality”.

This definition was the actual starting point for advocating environmental education worldwide. In the 1970s, the aims, objectives and approaches of the subject were specified, for instance at the *UN Conference on the Human Environment* in Stockholm, (1972), the *UNESCO/UNEP International Workshop on Environmental Education* in Belgrade (1975), and finally, at the *First Inter-governmental Conference on Environmental Education* in Tblisi in 1977 [12]. The notion of sustainable development was introduced in the 1980s. The *World Conservation Strategy* was launched in 1980 by IUCN, UNEP and WWF and pointed out the relationship between conservation and development. 1987 marked the year of the *UNESCO/UNEP Educational Congress on Environmental Education and Training* in Moscow, which endorsed the principles of the 1977 congress and included the term ‘sustainable development’ in the context of environmental education for the first time. In the same year, *Our Common Future*, the so-called *Brundtland Report,* of the WCED was published, further developing the concept of sustainable development and mentioning the importance of education for this process [11,9,13]. The *Earth Summit* of the United Nations in Rio de Janeiro was held in 1992 and it produced several significant documents. Agenda 21 forms the centrepiece, which represents the framework and provides guidelines for a global sustainable development. As mentioned before, the Agenda devotes a chapter of its own to education and refers implicitly to environmental education throughout the document. In 1996, the UN Commission for Sustainable Development decided on appointing UNESCO as task manager for the implementation of Chapter 36 [11]. The *Johannesburg Summit* 2002 and the proclamation of the *United Nations Decade of Education for Sustainable Development 2005-2014* constitute the latest milestones of the international development of environmental education so far [8,14].

In the course of the decades, environmental education has evidently experienced key trends. At the outset, the focus was set on pure nature observation. The 1970s were concerned with teaching conservation issues, only accounting for the ecological side of the environment [15,16]. A broader perspective was taken in the 1980s and 1990s by including the social and economic aspects of the environment into environmental education and embracing the concept of sustainable development. Alongside the change and redirection of contents, the approaches to teaching and learning were also modified. While disseminating and acquiring knowledge *about* the environment held a central position in the beginnings, it was later recognized that gaining personal experiences *in* or *from* the environment is essential for developing real understanding and concern for environmental issues. Today, the main goal of environmental education is to empower people and create a sense of stewardship by developing action- and decision-making competences. This enables students to take action *for* the environment and sustainable development, based on accurate knowledge about and experiences in the environment [17,18,9,16]. Consequently, a blend of all three approaches is needed for successful environmental education programmes.

However, closing the gap between rhetoric and realisation still remains the biggest challenge in environmental education. Even though international politics have identified the importance and key elements of environmental education and produced innumerable statements, decrees and recommendations, environmental education does not yet play the vital role it should. Formal education often relegates it to the fringe, or deals only with its cognitive aspects.

Informal education is mostly more adventure- and experience-oriented, but frequently lacks scientific input. Therefore, strategies for effectively implementing the international initiatives need to be further developed. The environmental concept of Galtür hopes to meet these requirements and contribute to closing the existing gap.

3. The Environmental Education Concept of Galtür

Galtür is a small Alpine village in the Paznaun valley, Tyrol, located approx. 1600m above sea level and representing a typical headwater area of the Alps. Like many high alpine settlements in the Eastern Alps, the former farming village is today a tourist resort, having undergone significant socio-economic and ecological changes since the mid-twentieth century [19,20]. In contrast to many other resorts, however, Galtür objects to pure mass tourism activities and tries to keep its growth under control [21].

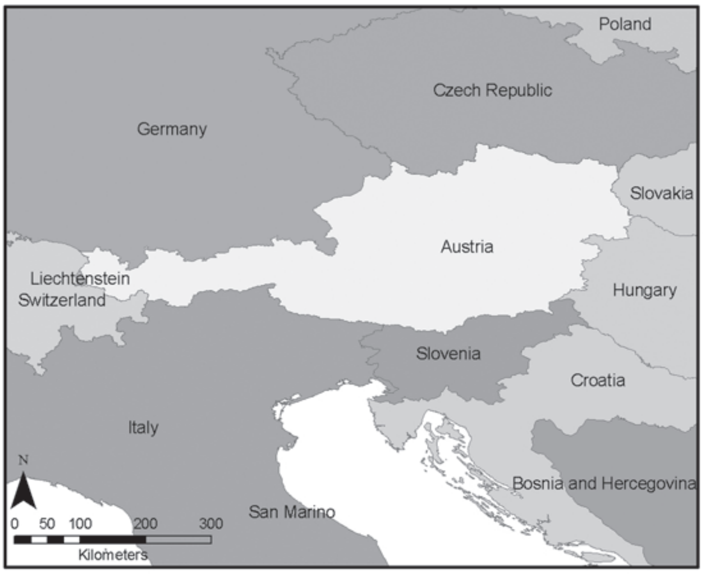

Figure 1. Geographical location of Galtür (Source: ESRI, 2003).

In February 1999, the village was omnipresent in the media after it had been hit by an avalanche of catastrophic dimension with 31 casualties [22,23]. Because of its far-reaching consequences, both in an economic and emotional sense, the catastrophe triggered a change in the perception of natural hazards in the village. This led to the wish to establish an environmental education and exhibition centre with a focus on the interaction between man, society and the alpine environment in order to contribute to a sustainable future of the Alps. By integrating the institution into a newly erected dam in the run-out zone of the 1999 avalanche, this plan is being realised [24,23]. First events have already taken place in the so-called 'Alpinarium', and an environmental education concept with an emphasis on geography and sustainability is being developed. Hence, a serious attempt of implementing Agenda 21 on a local level is made.

Figure 2. Aerial view of the Alpinarium (Source: Alpinarium Dokumentation GmbH, 2002.

The concept is characterised by a holistic approach, which takes man and the environment into account. By incorporating and combining geographical, pedagogic, sociological and psychological ideas and methodologies, the concept attains its unique and innovative nature. Additionally, new methods are being especially devised for the concept of the Alpinarium. Split into three parts, the approach assesses the educational potential of the Alpine environment, records the interest in the environment and develops implementation strategies. Thus, it answers the central research problem, which is: “What *can* society, what does society *want to*, and what *should* society learn from an alpine environment?”

Analysing and evaluating the alpine environment in regard to its educational value (i.e. educational potential) deals with the ‘can’ side of the question and regards the importance of the spatial context. For this purpose, a method for assessing the educational potential, a partial potential of the natural and cultural environment, is being developed [25,26]. This multistep - multicriteria procedure draws on aspects of physical and human geography, landscape ecology, spatial planning as well as didactics and includes logistic factors [27,28,29]. Furthermore, the method is incorporated in a GIS, allowing for the testing of different scenarios. The recording and analysis of the educational interest of society in an alpine landscape illuminates the ‘want’ side, gaining insight into the wishes, expectations and needs of individuals, groups and society as a whole concerning the alpine environment. A set of established methods of empirical social research is applied and adapted to the specific requirements of the concept [30,31,32]. This comprises distributing standardised questionnaires and conducting semi-standardised interviews as well as expert interviews. Subsequently, the results are interpreted.

The ‘should’ side of the research problem is addressed by the development of implementation strategies. The results of the studies on the potential of and interests in the alpine environment are combined and compared, current environmental issues relevant to Agenda 21 taken into account as well as logistic matters. Additionally, suitable teaching methods and media are adapted and co-operations set up with scientific and practice-oriented experts. With regard to community participation and capacity building, local residents are trained for environmental education work [33, 34, 10, 35, 36].

These three studies constitute the framework of the environmental education concept of the Alpinarium, which needs to comply with the distinctiveness of Galtür. Each pillar plays a decisive role in developing a concept especially tailored to the requirements of the Alpinarium and the village. Furthermore, the pillars illustrate how indispensable a combination of basic and applied research is for advancing the ideas and concerns of environmental education.

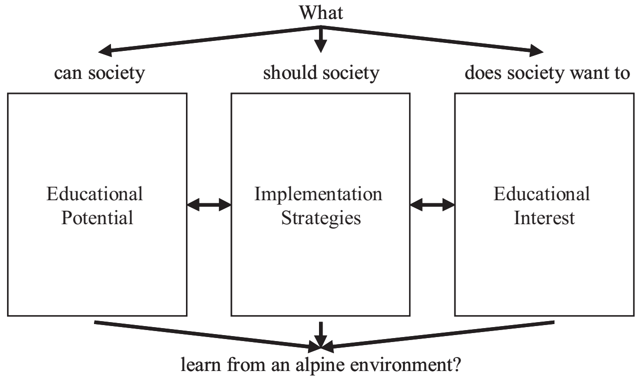

Figure 3. The three pillars of the environmental education concept of Galtür.

The concept needs to focus on a manageable number of core themes, which all reflect issues of highest concern for the Alps and their future development. The following selection modus based on six criteria was employed:

- *Target Group Orientation*
  The theme has to appeal to various target groups, e.g. local inhabitants, tourists, children.
- *Interdisciplinarity*
  The theme should have an interdisciplinary character, as this makes it possible to approach it from different points of view.
- *Experience-based Approach*
  Linking to personal, everyday experiences is essential for a theme.
- *Current Issues and Affairs*

Aspects of current alpine issues and affairs need to be inherent in a topic.

- *Feasibility of Implementation, Narrative Aspects*
  The implementation of a theme in environmental education programmes must be viable, and a theme has to possess narrative elements, in order to be successfully taught and experienced.
- *Spatial Context*
  A theme has to connect to the characteristics and processes of the region, especially as the environmental education concept of Galtür concentrates on outdoor activities.

These six principles are equally important for arousing interest in a topic and serve as prerequisites for environmental education in general [37,38]. This selection modus and an additional literature compilation led to the shortlisting of four core themes, which are interconnected. These are the topics: 'natural hazards', 'biodiversity', 'socio-economic change' and 'headwater'. As shown below, all six criteria introduced above applied to the core theme 'headwater' (see Figure 4):

- *Target Group Orientation*
  All groups of society depend on headwater; not only does the local population rely on it, but the lowland population, too.
- *Interdisciplinarity*
  Headwater issues are of major concern to many disciplines, e.g. geography, biology, engineering, economics. Thus, the complexity and the numerous aspects of headwater can be illuminated from different perspectives.
- *Experience-based Approach*
  All visitors to environmental education programmes offered in Galtür know about the significance of water, albeit disregarding the relevance of the Alps as a life-sustaining water tower.
- *Current Issues and Affairs*
  Agenda 21 acknowledges the importance of headwater protection and management, and the year 2003 was declared "International Year of Freshwater" [14]. Moreover, the Alpine Convention recommended the establishment of a 'water' protocol [39].

- *Feasibility of Implementation, Narrative Aspects*
  Implementing the 'headwater' theme is feasible, because its aspects can be explored in the Galtür region. Water and its effects are a recurring element in the oral and written history of the community.

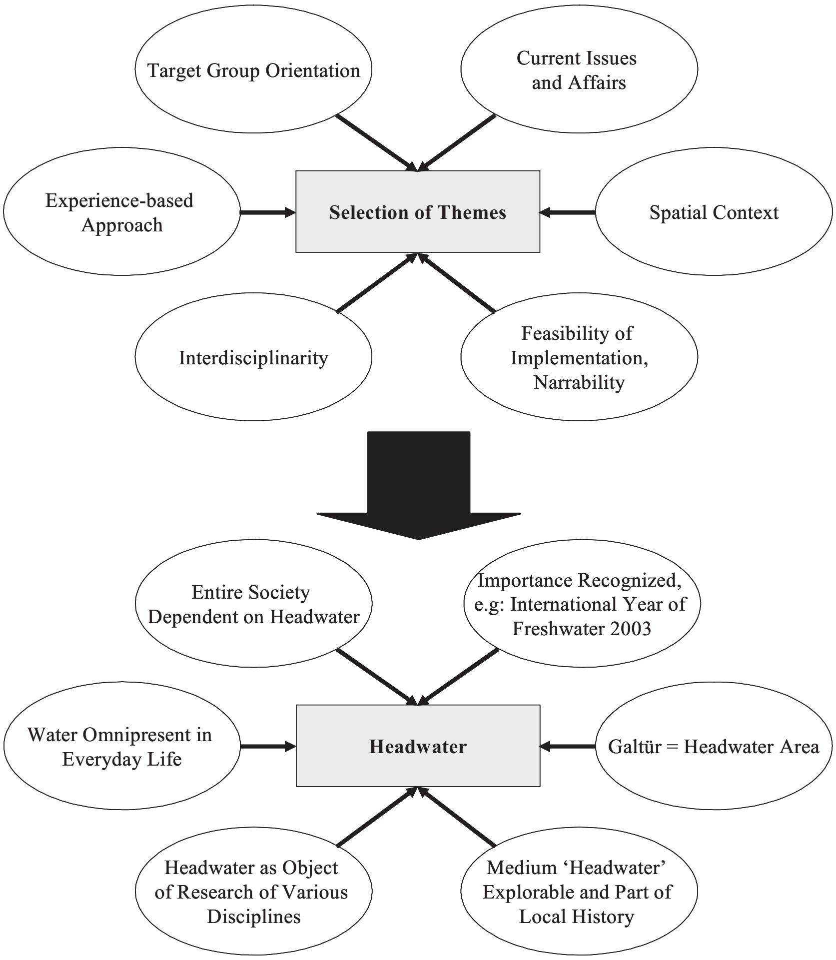

Figure 4. General selection modus for themes and modus applied to 'headwater' theme.

- *Spatial Context*
  Headwater in both its solid and liquid form, as well as parts of the natural and cultural environment associated with the theme, are ubiquitous in the Galtür area.

Pursuing the same selection procedure, three sub-themes were singled out, which stress different aspects of the theme ‘headwater’. These are the interrelated sub-themes ‘glacier’, ‘energy’ and ‘avalanche’. Glaciers are key features of mountain hydrology and function as natural water reservoirs [40,41]. In Galtür, the multiple roles of glaciers can be exemplarily pointed out. The use of headwater as a renewable energy source is common in the Alps [6]. Due to its proximity to hydropower facilities, Galtür is ideal for implementing the sub-theme energy. Moreover, the high water consumption has and will have a considerable impact on the community. Avalanches are a typical natural phenomenon in mountain headwater regions. They pose a serious threat to upland settlements, as tragically experienced in the case of Galtür [42]. Therefore, the sub-theme ‘avalanche’ is a high-priority issue for the environmental education concept of the Alpinarium, which, as mentioned, additionally contributes a theme of its own to the field of natural hazards.

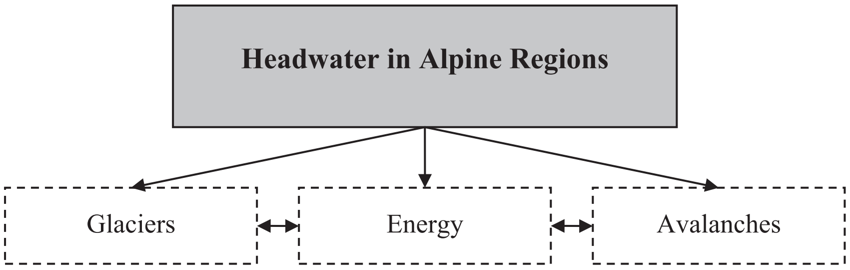

Figure 5. ‘Headwater’ sub-themes.

The themes and sub-themes were chosen on a provisional basis. The selection modus explained above and the literature compilation mark a first step. The studies on the educational potential, the educational interest and the implementation strategies investigate more deeply into the matter of themes and their results will reconfirm this preliminary decision.

4. Case Study: Implementing the Theme 'Headwater' in Galtür

How can the theme 'headwater' and its sub-themes be implemented in environmental education programmes in Galtür? In this short case study, possible ways of answering this question are presented. After explaining the general structure of the programmes and applying it to each sub-theme, adequate teaching and learning methods for environmental education are briefly introduced. These are illustrated by the contents of one module.

The sub-themes are once more divided and structured in a modular system, which comprises a basic module and several additional modules. The basic module gives a general overview and provides the fundamentals of the respective topic, while the additional modules delve into special aspects of the matter. The modules are applied depending on the interests, prior knowledge and wishes of a target group; the usage of the additional modules is optional. Naturally, all modules are related to each other and their contents and associated methods may overlap.

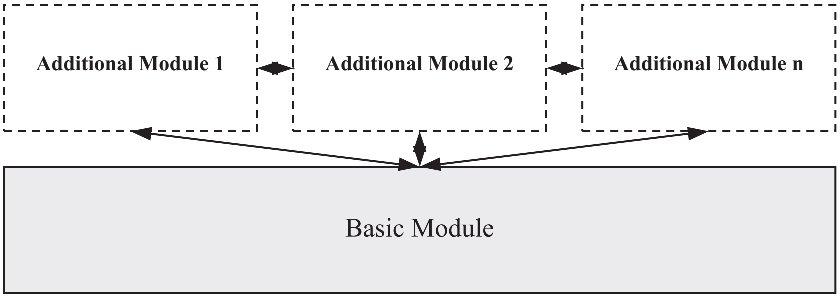

Figure 6. Modular system of implementation (number of additional modules can vary).

In the case of the glacier topic, the basic module engages itself with mass balance, glacier formation and other basic glacier elements, while additional modules are, for example, called ‘Water Tower’, ‘Climate and Glacier Change’ and ‘Glaciers and Tourism’. The latter three modules give insight into the role of glaciers in the hydrological cycle, point out the effects of climate change on glaciers and explain the tourist potential of glaciers. Further details on the contents of each of the four modules are given in Figure 7.

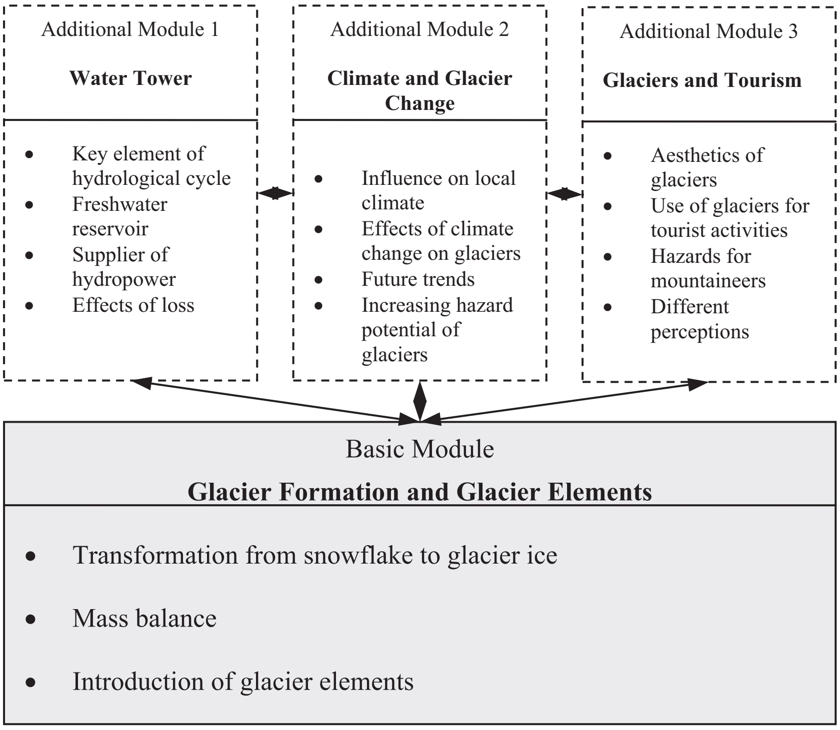

Figure 7. Structure and contents of ‘glacier’ sub-theme.

‘Energy’ is divided into the basic module ‘Topography and Hydropower’ as well as the additional modules ‘Energy and Socioeconomic Changes’, ‘Energy and Its Effects’ and ‘Sustainable Use of Headwater’. The contents of these components are, for instance, Galtür and its topography in respect to headwater, energy consumption, positive and negative effects of hydropower, ways of using and managing water resources wisely and in a sustainable manner.

The basic module 'Avalanche Formation and Classification' of the avalanche sub-theme is backed up by the following three additional modules: 'Avalanche Effects under Global Change Conditions', 'Avalanches and Protection Measures' and 'The Avalanche Event of 1999'. In this context, aspects of various effects on nature and society as well as management strategies are included. In module three, the contents of the other modules are exemplified by applying them to the 1999 avalanche event in Galtür.

Environmental education programmes need to incorporate the cognitive, affective and psycho-motoric dimensions of teaching and learning. A pool of methods is available for putting the above-mentioned contents into practice. This pool includes methods such as games, excursions, debates, discussions, quizzes and project work. When choosing the appropriate method for transporting and communicating environmental education issues efficiently and effectively, a set of criteria is to be observed. This set is composed of the main criteria 'target group', 'goal', 'contents', 'terrain' and 'logistics', which all determine the selection of a specific method decisively and form the centrepiece of any didactic analysis [43], [33], [37], [36]. All of the following questions need to be answered positively for a method to qualify:

- *Target groups*
  Does the method in question suit the target group in terms of age, abilities, group size and interests?
- *Goals*
  Can the short-term and long-term goals (i.e. awareness, responsibility for headwater issues and action for their sustainable protection and management) be reached by means of the method?
- *Contents*
  Does the method convey the contents of the theme?
- *Terrain*
  Is the method appropriate for the terrain (e.g. indoor / outdoor)?

- *Logistics*
  Does it make sense to employ this method with regard to time, climate and weather conditions, infrastructure, capacities and accessibility of the terrain?

Moreover, this decision-making progress affords regarding teaching principles, as these have formative and supportive influences on any learning and teaching progress. The principles of student-orientation, science-orientation, motivation, and activation belong, among others, to the constitutive factors of teaching [44].

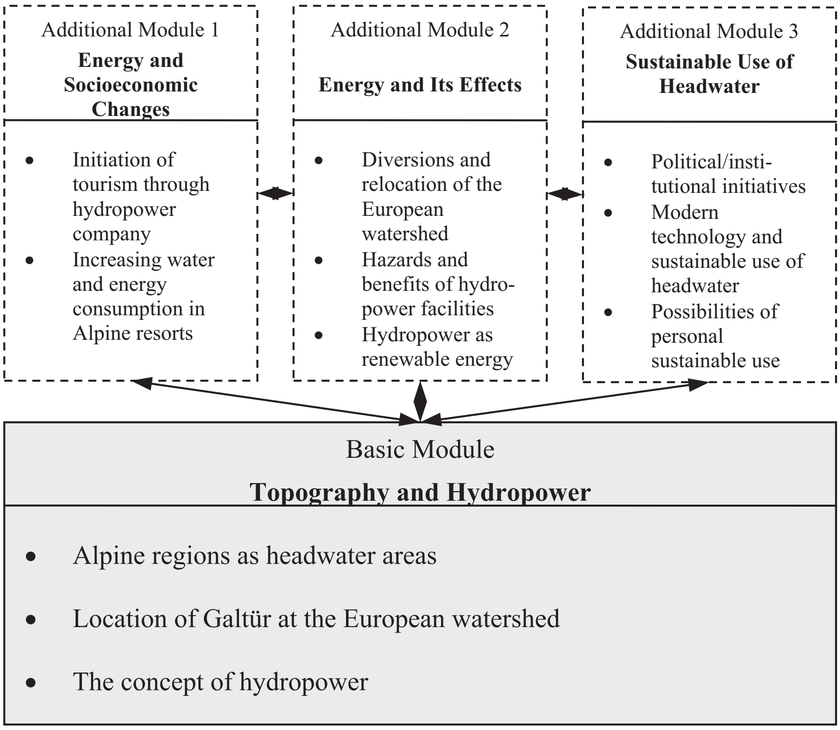

Figure 8. Structure and contents of 'energy' sub-theme.

The potential for linking content with method in an environmental education programme are illustrated by reference to the topic 'Key Element of Hydrological Cycle' part of the module 'Water Tower'. A group of adolescents (age 13-15) is taken as the target group, as these serve as most sustainable multipliers [45].

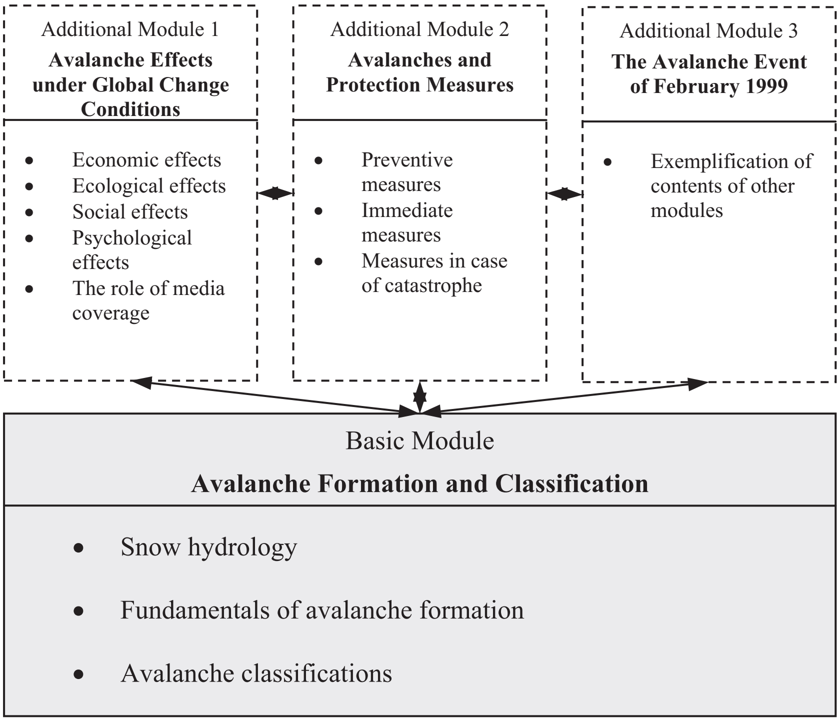

Figure 9. Structure and contents of 'avalanche' sub-theme.

The location is Jamferner, a glacier southwest of the village of Galtür. The method 'excursion' was chosen because an excursion suits adolescents, as it is action-based and includes adventure elements. The goal of creating awareness, understanding and concern for the 'headwater' theme is attained through personally experiencing the element glacier. Additionally, a trained guide can provide information and point out possibilities of protecting the glacier. By means of an excursion, the role of glaciers as key element of the hydrological cycle can be recognized when seeing, for instance, the features accumulation and ablation areas, equilibrium line, glacier meltwater and streams. Moreover, the method 'excursion' can incorporate several additional methods, such as measuring the discharge and its diurnal fluctuations. Due to safety reasons, a guided programme is obligatory when accessing a glacier with a group. Therefore, an excursion is highly appropriate.

Logistically, an excursion is always a great challenge, but Jamferner is easily accessible and a nearby mountain hut serves as refuge in case of sudden weather changes.

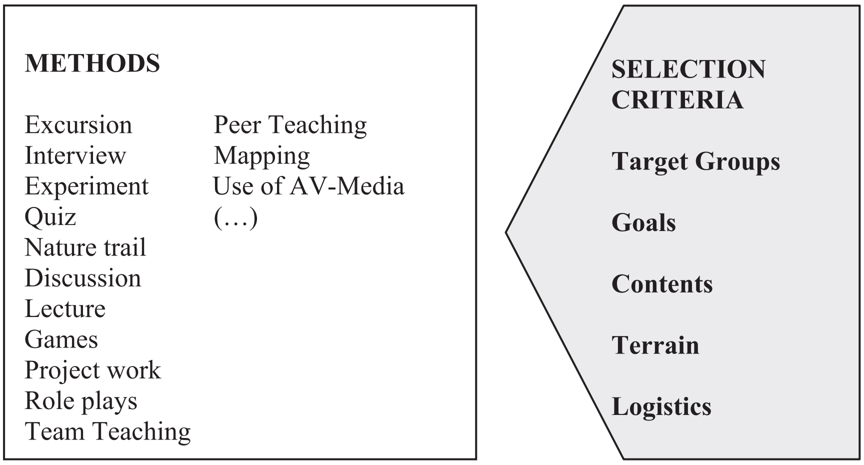

Figure 10. Selection criteria for methods.

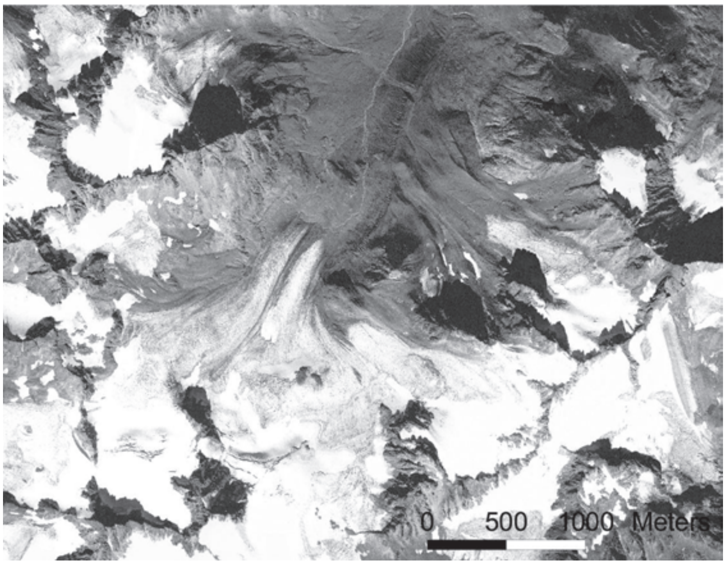

Figure 11. Orthophoto of Jamferner (Source: TIRIS, 2003).

5. Transfer Possibilities to Other Mountain Headwater Areas

The environmental education concept developed for Galtür can be easily transferred to other mountain headwater regions, as the central research problem ("What *can* society, what does society *want to*, and what *should* society learn from an alpine environment?") remains the same in any alpine area. Naturally, the concept needs modification to fit each particular region. When analysing and evaluating the educational potential of the respective environment, the matrices may have to be adjusted with regard to some parameters of the cultural environment. However, the empirical social research approach to assessing the educational interest of the alpine environment will stay the same as will the subsequent interpretation procedure. However, the actual questions will have to be adapted to the study area and its cultural context. As the development of implementation strategies depends partly on the findings of the other two studies, resulting programmes are likely to have slightly different emphases that better match the needs of the study area. However, the approach, its underlying principles, methods and method-combinations may be taken as standard. This will help other communities in mountain headwater regions develop their own sustainable environmental education programmes as an alternative to pure mainstream mass tourism. The main aim of this environmental education concept is to disseminate knowledge about mountain headwater regions, create understanding and concern for them and empower individuals to act on their own behalf.

6. Outlook

Headwater resources and headwater hazards are features of all alpine regions. The environmental education concept of Galtür acknowledges this fact and devotes a core theme to this subject. Glaciers, energy and avalanches possess both benefits and threats to the environment, which are reflected in the choice of contents for each educational sub-theme. This case study on implementing the 'headwater' theme in the environmental education programmes of the Alpinarium details options. Even though these options are based on selection modes, they need to be regarded as hypotheses. The three studies on the educational potential, the educational interest and on implementation aspects are underway and first results support the hypotheses. It is assumed that the preliminary choice of methods and themes will be reconfirmed by the further results of the studies. For example, 88 percent of the interviewees are interested in environmental issues.

Interdisciplinary approaches to environmental education which emphasise global change and sustainability are fundamental. State-of-the-art knowledge is a prerequisite for reinforcing enhanced social responsibility and the capacity to act for a sustainable future. Academia needs share its scientific findings with the public. This environmental education concept offers one route to this goal.

7. Acknowledgements

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HYDROLOGY OF WETLANDS IN THE HEADWATERS OF GREAT AFRICAN RIVERS

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KEYWORDS/ABSTRACT: African rivers / wetlands / dambo / headwaters / hydrological regime

African headwater wetlands (so-called dambos) play a significant role in the formation of the hydrological regime of great rivers in Central Africa. They act as spongy reservoirs capable of absorbing water during the rainy season and releasing it slowly during the dry season. The hydrological role of dambos, discussed in this paper, has been based on experiments performed in Zambia, as well as the research results accomplished elsewhere in Africa. Controversial opinions and conclusions concerned with the hydrological regime of dambos are commented and discussed.

1. Wetlands in Africa

The total area of African wetlands is estimated as 340,000 km^2. Among several types of classification, the following recognises wetlands according to their hydrologic properties [1, Table 1]. Each wetlands reflects its special morphological features. For example, Bangweulu swamp is a combination of lakes mixed with deeply rooted wetland vegetation, papyrus, and so called matete reeds. As for rainfall, some 1,130 mm/year has bas been estimated for the Chambeshi River as an inflow and 1,165 mm/year for the Luapula River as an outflow. The Chambeshi River itself is an ultimate source of the Upper Congo. However, the water balance calculation for African swampy areas is difficult because evapotranspiration from papyrus can exceed evaporation from free water surfaces. Hurst [2] had earlier claimed such a possibility, but without the support of direct measurements his conclusions were considered improbable. Subsequently laborious empirical studies, performed since the seventies, have confirmed his presumptions. Owing to the wetland composition, about 60 % of the total inflow is lost from Bangweulu by evapotranspiration. In fact, Bangweulu swamp functions rather like an artificial reservoir, transforming the hydrological regime of the Chambeshi into the modified regime of the river Luapula.

The Kafue flats are periodically flooded lowlands along a shallow river bed. Generally, such types of wetlands are seasonally saturated by the

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 203–210.

flooded river and slowly emptied during the dry season. Both inflow and outflow are dominant features. To function properly, a considerable amount of water is required, and therefore the flats are usually found in the middle stretches of the river rather then close to the headwaters. As can be seen from Table 1, evapotranspiration from the Kafue flats is 1,005 mm/year. Excluding the swampy area, it would be only 814 mm/year. Owing to much the less developed channel system inside the wetlands and the different vegetation, the loss as a proportion of inflow is much lower than at Bangweulu.

Parameter	Unit	Bangweulu swamps	Kafue Flats	Lukanga side wetlands	Dambo
Drainage area	km^2	102,000	58,290	19,490	1.43
Wetland area	km^2	15,875	2,600	2,600	0.15
Rainfall on the drainage area	mm/y	1,190	1,090	1,250	1,330
Rainfall on the wetland	mm/y	1,210	1,110	970	1,330
Evaporation from free water surface	mm/y	2,340	2,070	2,070	1,710
Additionally evaporated from wetlands	mm/y	1,120-1,260	196	252	-
Total evapotranspiration from wetlands	mm/y	2,000-2,180	1,005	1,120	1,075
Lost in % of inflow	mm/y	60	4	7,8	-

Table 1. Water balance calculation for selected African wetlands.

Lukanga, located in the centre of the Kafue basin and having a two-way connection with the main stream, is representative of side-stream reservoirs. The water balance calculation is difficult, considering the possibility that during the flood season there is a side spill of more than 500 million m^3 of water in an average year. Considering the very special morphologic features of such a type of wetland, the results cannot be widely generalised.

A dambo appears to be a negligible feature when its size is compared with the size of these other wetlands. However, the total number of dambos in Africa is estimated as 10^4 - 10^5 and most of them are located in the upper parts of major river basins, hence they play a significant role in African hydrology. This is why this paper is focused on the hydrology of dambos.

2. Dambo

Probably the first account of dambos was given by Ackermann [3], who described them as periodically inundated, stream-less grass-covered depressions on the headwater end of a drainage system in a region of dry forest or bush vegetation. According to Hindson [4], dambo is the native name given to the seasonally waterlogged grass-covered, treeless areas bordering the drainage line. It is worth mentioning that such wetlands are called „vlei“ in South Africa and „mbuga“ in East Africa. They are very distinctive features on aerial photographs of the headwaters of the Zambezi, Upper Congo and Upper Nile.

Hindson [4] stated that „Dambos remain wet in the dry season due largely to seepage which arises along the dambo fringe, this results from slow subsurface drainage from the upland area between dambos“. Such an observation is very important. The role of dambos in retarding runoff from headwater catchments may be important in the smoothing of the hydrological regime of great African rivers. In the early seventies. a basic question related to dambo behaviour was whether geomorphological conditions play a decisive role or whether the dambo vegetation is the key factor.

A definitive answer was obtained through laborious experiments in the Luano experimental catchments, established in the Zambian Copperbelt. These study areas consisted of 89.3-95.1% *Brachystegia* woodland with other species such as *Julbernadia* and *Marquesia,* and 4.9-11.3% dambo with some sixty species of grass. Such a composition was representative for the Kafue / Zambezi headwaters. The area formed a part of so-called Luano Forest Reserve, 12^0 34´S and 28^0 01´E, mean altitude 1300 m above sea level. Each of the catchments was less than 1.5 km^2 and located in the belt of 1270 mm mean annual rainfall.

During the first study phase, all basic hydrometeorological and hydrological parameters were measured using 40 rain gauges, 16 rainfall recorders, 4 discharge recorders with combined weirs and flumes, and 66 groundwater gauges. The soil moisture fluctuation was measured down to the depth of 7 metres in 45 soil moisture profiles. A complete meteorological station was established as well.

Already in the course of the first phase, a high variability in the annual rainfall was identified in small tropical catchments. Later, the regime was analysed by Balek [5] and the relationships between rainfall and other features were described by mathematical formulas.

An increase of the flood flow during the rainy season was observed in the second phase of the experiment when, after three years of observation, the trees were removed from two of four observed catchments. Two distinctly different groundwater regimes were observed in each experimental area. In the dambos, a rapid rise of the ground-water level was observed quite soon after the start of the rainy season. Then the groundwater level remained more or less constant because the dambo was fully saturated and rainfall contributed mainly to surface runoff. However, the groundwater level in the woodland started to rise two to three months after the start of the rainy season and continued to rise up to the end of the rainy season. The recession parts of the groundwater level record provided additional information on the dambo outflow pattern, particularly on evapotranspiration.

Soil moisture measurements were correlated with root measurements performed by Maxwell [6]. The results clearly indicated that the trees taped the water for transpiration through a shallow root system while it was available in the upper soil layer, for instance down to 3 meters. After the upper soil layer had been exhausted, a deep root system consumed water from deeper layers within the reach of the capillary zone above the groundwater level. Practically all rainfall water falling on the woodland was transpired from the *Brachystegia*, *Julbernadia* and *Marquesia* species.

Meteorological records were used for the calculation of potential evaporation by using Penman´s formula. All data served as input into the conceptual model „Dambo“. The model was developed with the aim to simulate various hydrological regimes of dambos and identify an optimal solution.

3. Results of the conceptual approach

Based on a systematic observation and simulation of the hydrological processes, following results were obtained by Balek and Perry [7]:

- A high fluctuation in the hourly, daily, monthly and even annual precipitation within the total experimental area of 10 km^2 was typical of this part of the tropics.
- The hydrological response of the catchment to precipitation depended on the area of dambos within each catchment.
- The dambos were recharged shortly after the rainy season had started and released the water within a constant time interval after the last heavy

storm. The length of the interval was dependent on the dambo soil type and on its slope.

- From a higher percentage of dambo area, a higher surface runoff occurred. Surface runoff formed the largest part of the total runoff in the catchments containing a dambo. The surface runoff was produced mainly as a result of the over-storage in the dambo aquifer.
- The duration of the surface runoff as compared with a non-swampy area of similar shape and size was delayed by the resistance of dambo grasses.
- Evapotranspiration from dambo grasses, however dense, was lower than from the woodland surrounding the dambo.
- Groundwater storage in the catchments was depleted more by evapotranspiration than by river base flow. The evapotranspiration by the woodland was approximately three times higher than the evapotranspiration by the dambo grass. Therefore, only a part of the woodland area, consisting of the mixture of trees and grass and therefore called a transitive region, contributed to the hydrograph formation.
- The ratio E_t / E_o (potential evaporation / actual evapotranspiration), was variable year to year and month to month, and dependent on the availability of groundwater, soil moisture fluctuation, and precipitation distribution. It seems very likely that *Brachystegia* and relative species can transpire up to 90% of the potential evaporation, and the ratio E_t / E_o can exceed 1.0 during the rainy season.
- From these results, it can be concluded that the small wetlands - dambos, located in the headwaters of great African rivers, play a unique role in the formation of their hydrological regime. This is because the thick grass cover of the dambos delays the surface flow which has been produced by the over-stored dambo aquifer, and thus contributes toward the stabilisation of their hydrological regimes.

4. Dambo as a continuing challenge

After the publication of previous results by Balek and Perry [7], the authors were informed that during the second phase of the experiment, when the *Brachystegia* forest, surrounding two experimental dambos, had been cleared, flood volumes and surface runoff from respective catchments increased significantly. This was considered as a confirmation of the woodland’s role. All catchments had behaved as anticipated.

After the termination of the Luano experiments, dambos have continued to be considered a hydrological challenge and much attention has been paid to the role they play on the African hydrological scene. Bullock [8] reviewed some thirty papers, focused on various dambo processes in other parts of Africa. Very few however, if any, were based on direct observation and experiment. Bullock also analysed the relevant literature in [9] and summarised his conclusions on the role of dambos:

- Dambos appear not to be a critical factor in determining annual runoff from catchments at the regional scale.
- There is no significant persistence in annual time series or reduction of the annual variability of flows that can be related to varying dambo density.
- Base flow and low flow analysis show that the areas of dambos within a catchment is not a critical factor in determining base flow and dry season flows (at least at the national scale in Zimbabwe“).
- There is no evidence to suggest that dambos significantly contribute to the maintenance of base flow or dry-season flow regimes.
- There is no significant influence exerted by dambos in reducing or increasing either the magnitude or variability of annual maximum instantaneous flood discharges either at the national scale or within particular soil classes.

Furthermore, Bullock [9], after reviewing data and conclusions from past studies, stated that dambos are considered to be important in the hydrological cycle „....because of their extensive distribution in headwater regions....“. He concluded: „....that the mechanisms and processes by which the dambos determine the movement of water are poorly understood.“

5. Conclusions after thirty years

From time to time, the author of this paper has had an opportunity to visit the Luano experimental areas. Among other features, he had a chance to see the second phase of the project, conducted by late Molnar [10], particularly the land use change by clearing the woodland along two of four observed dambos. After another eight years, he was pleased to spot in once cleared areas the growth of new trees, After some twelve years, he discovered that, in then already deserted experimental areas, local African observers were still performing their duties, almost as a sort of religious rite.

The author can not agree with the statement that the mechanisms and processes of dambos are poorly understood, at least not in the Luano catchments. It is improbable that in the near future similar experiments will be repeated elsewhere. In addition to the hydrologic results, the systematic training of Zambian observers and hydrologists can be considered as beneficial to the human resources development in Zambia.

As for Bullock's conclusions about dambo extent being an unimportant factor in relation to the regional base flow and dry season flow, these cannot be accepted fully. In areas without dambos and covered entirely by the woodland, much of the precipitation is spent on evapotranspiration instead of contributing toward the formation of prolonged surface runoff. An example taken from the Luano project is given in Table 2.

Month	Evapotranspiration			
	Dambo		Woodland	
	E_t (mm)	E_t / E_o	E_t (mm)	E_t / E_o
October	6.58	0.03	49.05	0.24
November	80.72	0.53	85.39	0.56
December	86.36	0.66	129.04	0.99
January	87.50	0.59	153.16	1.03
February	67.54	0.55	163.75	1.32
March	64.14	0.47	193.66	1.42
April	29.26	0.21	192.72	1.39
May	20.40	0.17	119.82	0.99
June	9.17	0.09	82.47	0.83
July	9.63	0.09	72.49	0.67
August	6.65	0.05	68.09	0.52
September	5.84	0.04	56.23	0.36
Year	473.79	0.29	1356.87	0.83

Table 2. E_t *and* E_t / E_o *ratio in a year with annual precipitation equal to 1620 mm.*

Delay of surface runoff, caused by the thick grass cover in dambos, has been traced by *in situ* experiments and observations. It is clear that the shallow soil profile underlining the dambos, together with the groundwater stored in the non-capillary pores up to the soil surface, create conditions which are not favourable for the growth of woodland. Therefore, dambos tend to support grassy aquatic environments capable of extending surface runoff process. Thus precipitation, morphology, and vegetation play a complex and unique role in the hydrology of dambos and have positive impact on the hydrologic regime of major African rivers.

Fortunately, recent developments in central and southern Africa indicate that, in the near future, more attention will be given to the protection of dambos, at least in the Limpopo and Zambezi basins. Hopefully, the Luano experiments, conducted long ago in a remote part of the Central African Plateau, will yet serve to encourage future systematic and experimental research focused on the hydrology and effective land use of similar wetlands in African and other parts of the world.

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HEADWATER WETLANDS IN EASTERN AND SOUTHERN AFRICA

The Evolving Debate

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KEYWORDS / ABSTRACT: Headwater wetlands / sustainability / socio-economic needs / environment / policy

This review makes clear the need for the development of sustainable use regimes in wetlands to achieve a balance between environmental and socio-economic needs. However, the extreme perspectives of pure conservation and total development are still held by many actors. In addition, wetlands fall under the jurisdiction of different agencies which have varying perspectives on how these areas should be used, and are often in conflict with each other. In many countries, governments still do not have clear policies on wetlands and are torn between what they need to do to meet production and development goals and what they feel is required for responding to environmental concerns. Experience in Eastern and Southern Africa suggests that two key areas, in particular, require attention if headwater wetlands are to be managed in an ecologically sound and economically viable way. One of the key challenges is for the development of appropriate government policies which identify the need for a balanced approach to wetlands. Rather than taking one of the extreme positions on the continuum of views and imposing a blanket policy, it is necessary to recognise the diversity of wetlands. This means that some wetlands may need to be preserved in a pristine condition or with minimal transformation, but others may be suitable for careful transformation to a mix of uses and some may be transformed completely. To develop the land and water management regimes needed to achieve sustainable use will require using all of the resources available. This includes both the local knowledge and local institutions rooted in the communities, as well as more recent technologies from the extension services and research stations. Further, in line with decentralisation, which is occurring in many countries today, it will be necessary for local communities to be empowered and given appropriate responsibilities in relation to government agencies in the integrated management of watersheds. Only in such a way can economically attractive and ecologically efficient management of headwater wetlands be achieved.

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 211–220.

1. Introduction

This overview of some of the major debates and issues in the management of wetlands in Eastern and Southern Africa draws on a variety of sources ranging from international debates [12, 23, 24, 31] through country studies [8, 22] to fieldwork from researchers [37] and NGOs [5]. The discussion refers to wetlands in general, but given the plateau and mountainous terrain in much of this region, many of the wetlands are headwater ones, either being on zero order streams or in the upper reaches of extensive river systems.

2. Different Views about Headwater Wetlands

A continuum of perspectives can be identified concerning wetlands in Eastern and Southern Africa. At the extremes of this are conflicting views of wetlands as an agro-development resource or as an environmental conservation asset.

The immediate development situation, namely poverty and food insecurity, drives the thinking with respect to the first of these perspectives. In this part of the world, where rural populations are still growing and land degradation is occurring, especially in highland areas, there is a search for new agricultural land. This is increased by commercial farming opportunities as markets grow, communications improve and as technologies develop. In this situation, wetlands, especially the smaller ones in low order streams, are becoming a new "agricultural frontier", with both spontaneous and planned development taking place on them. In particular, for small-scale and subsistence farmers, wetlands can help address food insecurity because they can provide a supplementary harvest in the late dry season or early rains which is the "hungry season". Trends towards this sort of use of wetlands are seen especially in countries where there are serious demographic pressures and declining upslope productivity, such as Rwanda, Uganda, Ethiopia, Kenya and Malawi, but this phenomenon is also more widespread [12, 34]. Estate development of wetlands has typically been in the larger wetlands lower down the river system, but increasingly commercial use of wetlands in the middle and upper parts of river systems is occurring as in Rwanda and Uganda.

At the other end of the continuum, the conservation view of wetlands is held by several international and domestic actors. It is strongly supported by the Ramsar Convention Bureau which, over the last five years, has been trying to ensure that all African countries become members of the convention and designate one or more wetlands as protected areas in order to fulfil the membership criteria. In such wetlands, wise use, primarily sustainable collecting of vegetation and fish, is the only use seen to be acceptable, with some involvement of local communities [30]. This view point is driven by the concern that the transformation of wetlands, for cultivation and other uses, will have irreversible negative environmental impacts – especially on biodiversity, migratory bird species and hydrological functioning (although the latter tends not to be recognised so much by conservationists). This has led to the development of wetland policies which focus on the conservation and preservation of all wetlands, as in Zambia [18], or the development of a national policy which seeks to reduce the use of wetlands and increase the number under conservation and wise use regimes, as in Uganda [16]. Other international agencies with similar views to the Ramsar Bureau include Birdlife International, the Worldwide Fund for Nature (WWF), and the World Conservation Union (IUCN). In some instances, the issue of development is beginning to be recognised by some of these agencies and their projects do include consideration of some limited developmental activities in parts of wetlands. In other cases, those concerned with conservation now emphasise the rehabilitation of degraded wetlands [15].

An emerging middle view seeks to achieve the sustainable use of wetlands for the long-term benefit of the communities, addressing development issues, such as food security, whilst minimising the environmental changes and impacts [35, 36]. This includes a variety of perspectives starting with the Mondi Wetland Project in South Africa which focuses on wise uses and only limited agriculture with crops suited to flooded conditions – such as taro (yams) (*Colocasia esculent*) in order to maintain the hydrological regime [26]. In Uganda, the national wetlands programme, as well as seeking to reverse the excessive transformation of wetlands which has occurred, also supports wetland planning to achieve more "balanced" land use within wetlands and seeks to rehabilitate those which are degraded. In Ethiopia, a local NGO, dairying for the domestic market, tea estates for export, and the provision of land for small-scale market oriented production of vegetables and rice has been encouraged since the 1970s [9, 21].

Food shortages have also driven governments to focus on wetlands with specific policies aimed at increased production from these areas to compensate for poor upland harvests. For example, since 1985 one of the regional governments in Ethiopia has regularly established Wetland Task Forces in the wetter parts of the country in years of poor national harvests to try to increase food production [38]. Malawi has also developed a policy of encouraging dry season irrigation in seasonally flooded or moist dambos as part of a response to the 2001/2002 famine, while Zambia's national irrigation policy has a similar focus [14, 19].

2.1. DONOR AND MULTILATERAL AGENCY SUPPORT

International donors have often supported national efforts to transform wetlands and make "fuller" use of these areas. During the 1970s development assistance from the Netherlands supported the drainage and development for agriculture of the Kisi wetlands in western Kenya, a project which was of limited success due to problems with acid sulphide soils [13, 28]. A more sensitive approach to wetlands may be developed by the Nile Basin Initiative, the biggest programme of donor supported development in Eastern and Southern Africa. In seeking to ensure the efficient use of this river system, wetland management is one of the elements which has been recognised to need attention. So far the Initiative has tended to focus on the issues related to the Sudd and the other large mid-stream wetlands, but it does include projects on the management of catchments and this will include headwater wetlands.

Other multilateral agencies involved with wetland development initiatives over the last decade have included FAO and the International Water Management Institute (IWMI). One of FAO's initiatives has sought to link countries in Eastern and Southern Africa in its efforts to achieve the sustainable agricultural development of wetlands [12, 23]. FAO's emphasis is upon sustainable land use management for improved food security, in line with its emphasis on agricultural production. A more recent initiative has come from the International Water Management Institute (IWMI), one of the CGIAR research centres, which established an Africa office in the late 1990s in Pretoria. Due to IWMI's original concerns with rice management in Asia, its emphasis is upon the efficient use of water [20].

2.2. COMMUNITIES – THE MAIN ACTORS

While government and international agencies are formulating policies concerning wetlands, communities are themselves developing their own ways of using these areas in response to the changing demographic and commercial situations. In many cases, it appears that it is the richer members of communities who are appropriating the formerly communal or open access wetlands, as market opportunities encourage their use [9, 3, 39, 33]. In other cases it appears that it is more the poorer households who are using wetland margins with limited technology to diversity their survival strategies either through subsistence production or through semi-commercial production for local markets [27, 32]. Such spontaneous development of wetlands is rarely supported by government technical assistance and the use regimes have to be developed by trial and error drawing on indigenous knowledge systems where these exist [10].

3. The Need for Sustainable Management of Headwater Wetlands

This expanding use of wetlands raises many challenges due to the frequently fragile nature of these areas and their potential for degradation as cropping and grazing develop. In particular, there are concerns that as wetland use intensifies, degradation will occur, curtailing the role of the wetlands in the hydrological system so that stream flows become more variable and the range of benefits the wetlands produce for communities is reduced. In extreme cases, "terminal" uses, such as the planting of eucalyptus and mining for sand extraction and brick making, may occur in wetlands completely altering the characteristics of these areas [37].

With such threats, there is a growing need to explore how to prevent wetland degradation and achieve sustainable use, or how to rehabilitate wetlands so that their various ecological functions and economic benefits can be recovered. Some experience of this is beginning to be found at different sites through Eastern and Southern Africa. For instance, the Uganda Wetland Programme has been working with communities to help them reconsider the state of their wetlands and at Kumi has helped the community return to a less intensive and more diverse pattern of wetland use, than has been the case in recent years. This holds the potential for greater sustainability and more social equity (Bakema, et al, in press). In Ethiopia, studies have shown that sustainable use of wetlands for a range of uses is possible based on the local knowledge of communities who have developed a sensitive understanding of these areas over generations. This includes well-vegetated and carefully managed catchments, control of the water table to prevent over-drainage, mixed land use in the wetland with areas of natural vegetation, and replication of the natural flooding with the wetland hydrology altered for the minimum period necessary [1]. The Mondi Wetland Project in South Africa is also showing large- and small-scale farmers the importance of wetlands and trying to encourage better land use with a limited range of activities [26].

There are examples of the need for wetland rehabilitation in many areas throughout the two regions considered here in order to try to improve the livelihoods of people whose wetland have been destroyed. For instance, in the highlands of northern Ethiopia desertification has been increased due to the removal of wetlands by eucalyptus planting [40], while in western Kenya on the foot slopes of Mount Elgon wetland removal for cultivation has led to increased flash flooding [13]. Similar flooding problems, with serious impacts on infrastructure, are found in Malawi as a result of dambo degradation, while in Rwanda there has been serious destruction of the wetlands in the Rugezi area where settlement of displaced persons has damaged both catchments and wetlands.

Re-instating wetlands into the landscape can be an important part of a wider process of environmental recovery, to recreate a more efficient and productive resource base. This can improve domestic water supplies by returning the ground water table to higher levels so ensuring the regularity of stream flow and reduce flooding and its attendant damage to infrastructure. However, wetland re-instatement needs to be supported by catchment rehabilitation, and that will require a holisitic approach to both land use management and rural livelihoods development. A holistic approach is also needed with knowledge systems and institutions, drawing on the most appropriate aspects of indigenous and government systems.

While wetland recovery should have positive impacts, negative changes may occur. This is especially likely if malaria and bilharzia are present as these can become health hazards. Consequently, careful management of wetlands and human interaction with them is needed in rehabilitation measures, as well as when seeking to achieve sustainable use [29].

4. Some Concluding Challenges in Headwater Wetland Management

The above discussion makes clear the need for the development of sustainable use regimes in wetlands to achieve a balance between environmental and socio-economic needs. However, the extreme perspectives of pure conservation and total development are still held by many actors. In addition, wetlands fall under the jurisdiction of different agencies which have varying perspectives on how these areas should be used, and are often in conflict with each other. Indeed, in many countries, governments still do not have clear policies on wetlands and are torn between what they need to do to meet production and development goals and what they feel is required for responding to environmental concerns.

Experience in Eastern and Southern Africa suggests that two key areas, in particular, require attention if headwater wetlands are to be managed in an ecologically sound and economically viable way. One of the key challenges is for the development of appropriate government policies which identify the need for a balanced approach to wetlands. Rather than taking one of the extreme positions on the continuum of views and imposing a blanket policy, it is necessary to recognise the diversity of wetlands. This means that some wetlands may need to be preserved in a pristine condition or with minimal transformation, but others may be suitable for careful transformation to a mix of uses and some may be transformed completely [11, 3].

The other major challenge is to develop appropriate technologies for sustainable wetland management, especially for community use. This process must include recognition of the need for a holistic landscape approach, with catchment management considered as an integral part of the land and water management regime which affects wetlands. To develop the land and water management regimes needed to achieve sustainable use will require using all of the resources available. This includes both the local knowledge and local institutions rooted in the communities, as well as more recent technologies from the extension services and research stations. Further, in line with decentralisation, which is occurring in many countries today, it will be necessary for local communities to be empowered and given appropriate responsibilities in relation to government agencies in the integrated management of these areas [3, 37]. Only in such a way can economically attractive and ecologically efficient management of headwater wetlands be achieved.

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ECONOMIC CONTRIBUTION OF HEADWATER WETLANDS:

Experience From Western Ethiopia

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KEYWORDS / ABSTRACT: Headwater wetlands / human interventions / environment / local economy

The environmental role of headwater wetlands is increasingly influenced by human interventions in many parts of the developing world. The way in which wetlands and their catchments are managed is affected by the perception of these areas by people and by their abilities to obtain benefits from them using varying technologies in response to changing opportunities. Wetland use in western Ethiopia appears to have a long history although the evidence for this is fragmentary. During the 20th century wetland cultivation has increased to different degrees in different parts of the region. Agricultural development has been most intense in the north and east of the study area. Agricultural development of wetlands has been stimulated through the 20th century by technological innovations, demographic change, commercialisation and government policies. Other aspects of government policy have also affected wetlands. The extension policy since the mid 1980s has stressed the need for improving food security. In the wet south-west highlands this has focused upon the draining of wetlands. Today wetlands are a significant part of the resource base in south-west Ethiopia and are used by virtually every household in some way. A recent assessment of the role of wetlands throughout much of the study area (ref) has shown that wetlands play a critical role in food security. Research findings suggest that degradation of wetlands is not only, or necessarily, linked to increasing intensity of use. Other factors such as catchment land use, wetland soil depth, and local geomorphological features strongly influence the eco-hydrological characteristics of each wetland, and hence their capacity to support different forms of wetland use. Therefore to get sound environmental management need to recognise the economic role which wetlands play in these headwaters and how they interact with the catchments and downstream.

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 221–232.

1. Introduction

The environmental role of headwater wetlands is increasingly influenced by human interventions in many parts of the developing world. Rural population growth, improved communications and market access, as well as changing technology, have all led to increased use by communities and investors of wetlands higher up the river systems and to land use changes in the catchments which impact upon wetlands. The way in which wetlands and their catchments are managed is affected by the perception of these areas by people and by their abilities to obtain benefits from them using varying technologies in response to changing opportunities. Hence in any attempt to influence the environmental role of headwater wetlands today, the perspectives of the users of these areas and their catchments must be explored and they must be fully involved in any discussions and planning about the future of these areas. In fact local communities have much to offer in the search for appropriate and sustainable use of headwater wetlands and their catchments as they have often a body of local knowledge which can provide specific management techniques for sustainable use, while they may have local institutions with the capability of helping communities manage land use in ecologically sound ways.

In headwater management, it is important to understand the role that wetlands play in the local economy and to take a holistic perspective, both in terms of economy and society and in terms of land use. This holistic perspective must not just focus on headwater areas but also consider the downstream implications of changes in wetland use.

The contribution of headwater wetlands to socio-economic development is still poorly understood, but probably reflects the aspects of the changing development situation in headwater areas. These wetlands were possibly once place of refuge for the poor when they were unable to obtain adequate land in the headwater areas or were squeezed out from other more attractive upland sites by population growth or social and political pressures. However, it seems that increasingly these areas are a frontier of opportunity for the rich as it is the better off who have the political power to appropriate formerly open access resources and who have the resources and technology to develop the use of these areas. Hence, managing these areas and seeking to achieve sound and sustainable use of them, is not just a matter of recognising the role local communities and indigenous knowledge in achieving the sustainable use of these areas, but also one of understanding the socio-economic processes taking place in these areas.

This paper explores this interaction between wetlands and catchment users using the case of headwater wetlands in Western Ethiopia (hereafter the study area). It shows that wetlands fulfil a range of roles in the local economy and more widely as the area is increasingly integrated into the national economy and subject to population growth. Economic and demographic pressures in the uplands, as well as opportunities in the wetlands are leading to the development of these areas, while government policies are also important influences. Although there is a general tendency toward the degradation of wetlands as a result of agricultural use, there is also some evidence of practices which can lead to sustainable use of these areas and the maintenance of their ability to function to some degree as water stores like pristine headwater wetlands.

2. Highland Wetlands of South-west Ethiopia

The highlands of south-west Ethiopia are a dissected plateau of between 1,500 m a.s.l. and 2,300 m a.s.l. This area includes the headwater catchment for the Baro (Sobat) river, the second most important tributary of the Nile from Ethiopia, and includes part of the catchment of Blue Nile, the most important Ethiopian tributary for the Nile (Figure 1). Rainfall varies from 1000mm in the east and north of these highlands to over 2000mm in the higher central part, with a single rainy season lasting from six to nine months (March to November). The natural vegetation of most of the area is broad-leafed tropical montane rainforest. The forest has an under-storey of wild coffee (*coffea arabica*) in many places, as well as a ground cover which includes spices, such as Ethiopian cardamom (*Aframomum korarima*). Much of the forest in the northern and eastern part of the area (Wellega and Jimma), has been cleared since the early 20th century, and the forest in the southern part (Illubabor and Keficho) has been subject to growing degradation since the 1960s. Forest clearance has been stimulated by population growth and in-migration, as well as new roads and increased production of coffee.

Despite globalisation, the bulk of the agricultural production in this area (excluding coffee) is for subsistence use, with only a small percentage sold. Maize is the most important staple, with root crops such as taro (Coles) more common in the wetter and more forested parts of the region. Tef *(Eragrostis tef)*, the staple of northern Ethiopia, has been introduced in some localities but its small seeds and the fine tilth, which its cultivation requires, is leading to serious erosion [5].

Three major types of wetlands have been identified in the area: valley head, mid-valley and, larger, floodplain wetlands. The valley head wetlands of less than 30 ha are the most common, followed by mid-valley wetlands of a similar size. These wetlands account for between 1% and 2% of the area, although if other types of wetlands are included, such as floodplains, this would probably rise to approximately 4-5% [1, 2].

The sedge (*Cyperus latifolius*), locally called *cheffe*, dominates most of the wetlands in their natural state, while larger wetlands are also fringed by the swamp palm (*Phonex reclinata*). Although the larger wetlands remain inundated for most of the year, the smaller valley-head and mid-valley wetlands are flooded for varying lengths of time, during the height of the rainy season [3]. These smaller wetlands are the most common in this area and because of their size they are most subject to human intervention, including cultivation. In contrast most of the larger floodplain wetlands are little used apart from collecting activities.

3. Use and Dynamics of Headwater Wetlands

Wetland use in western Ethiopia appears to have a long history although the evidence for this is fragmentary. Since the earliest period of human settlement it is likely that the sedges in the wetlands have been collected for the thatching of ‘tukuls’ (huts) and the creation of field shelters for guarding crops. The sedges and leaves from the wetland fringe palms have also been used for many centuries for craft activities such as basket making. Knowledge of the medicinal value of several wetland plants suggests that there has been an intensive interaction by at least some specialists with the wetland vegetation for many centuries.

Travellers to some part of this area in the early 19th century report the intensive cultivation of wetlands (REF see McCann) while recent coring of presently cultivated wetlands show a cultivation soil buried under a metre or more of upland deposits and the present soil strata. This can be interpreted as showing past cultivation when the population was greater and there was a shortage of land probably in the mid 19th century before the population crash following the conquest of this area and its incorporation into the Ethiopian state in the later 19th century [12].

This use of wetlands has been tempered by the health hazards associated with them, although these are limited in most parts of the region by altitude which makes the temperature too low for malarial mosquitos to breed. Nonetheless, liver fluke for cattle and some tick transmitted diseases for humans are major hazards in these areas and they have led to communities as a whole to avoid intensive interaction with and residence close to the wetlands.

During the 20th century wetland cultivation has increased to different degrees in different parts of the region. Agricultural development has been most intense in the north and east of the study area with most of the wetlands in Eastern Wellega and Jimma drained and often degraded so that they are mostly used as rough grazing land. In Western Wellega, the wetland here are also fully cultivated but due to particularly severe upland degradation – mostly associated with tef cultivation the wetlands are still in use and are quite carefully managed, these being the main source of agricultural production in this locality. In Illubabor, the small headwater wetlands are in varying stages of use as population pressure and forest clearance impacts upon them, while in wetter Keficio area to the south most wetlands are uncultivated and there is only limited taro cultivation, there being little land pressure here and very heavy rainfall (2,000mm) which makes wetlands difficult to use of farming.

4. Development of Wetland Agriculture

Agricultural development of wetlands has been stimulated through the 20th century by technological innovations, demographic change, commercialisation and government policies. In the early part of the century, a herringbone pattern of drainage was introduced that allowed communities to drain the whole wetland, rather than just its margins [12]. In the first two decades of the 20th century, this technology was used by farmers to respond to demands from landlords to increase crop production in response to local food shortages caused by poor rainfall and pestilence.

Later, the expansion in coffee cultivation saw landlords require peasants to cultivate wetlands to release arable land on the interfluves for coffee planting. The coffee trade also led to the growth of an urban population and this has provided a market for green maize, tef and vegetables, which are wetland crops.

This has been particularly dangerous for wetland sustainability as it has led to double cropping with tef or vegetables preceding maize and a total drainage period of 9-10 months from September to June/July.

After the 1974 socialist revolution, land redistribution in search of equality led to most farmers holding wetland plots which they had to use in some way to prevent re-allocation. More purposeful and intensive wetland cultivation was also encouraged at this time by some specific government actions, notably the introduction of quick maturing maize varieties, which improved the success of wetland cultivation, and the spread of the Irish potato, a new crop which happened to be suited to wetland farming. There were also impacts upon wetlands from the severe 1984 famine in northern Ethiopia, which led to half a million famine victims being resettled to the south [12]. In the south-west, some of these settlers were allocated unwanted wetlands by local communities and had to learn quickly how to manage these areas.

Other aspects of government policy have also affected wetlands. The extension policy, since the mid 1980s, has stressed the need for improving food security. In the wet south-west highlands this has focused upon the draining of wetlands. This has been pursued with "vigour" in years when there have been poor harvests in any part of the country. To implement this policy, Wetland Task Forces have been established at different administrative levels and each farming community is given a target area to drain for cultivation.

Finally, a growing pressure upon wetlands comes from cattle grazing. Although the number of cattle is not large in most of the south-west, they are increasingly common in many localities as a result of coffee income and the loss of land investment opportunities due to land nationalisation in 1975. Increasingly complete cultivation of uplands forces the cattle to use the lower wetlands for more than just the dry season with serious damage to wetland soils and their water storage due to soil compaction.

5. Current Use of Wetlands

Uses	**Estimate of Households Benefiting**
Social /ceremonial use of sedges	100% (including urban dwellers
Medicinal plants	100% (mostly indirectly by purchase from collectors / traditional doctors)
Domestic water from springs	50% - 100% (depending on the locality)
Thatching sedges	85% (most rural households)
Temporary crop guarding huts of sedges	30%
Water for stock	most cattle owners, c 30 % of popn
Dry season grazing	most cattle owners, c 30 % of popn.
Cultivation	25%
Craft materials (palm products & sedges)	5%

Table1. Wetland uses and beneficiaries in Illubabor.

Today wetlands are a significant part of the resource base in south-west Ethiopia and are used by virtually every household in some way [7] (see Table 1). Wetland edge springs are the major source of water throughout Illubabor and in many other parts of the study area, while sedges are used by all households on holidays to cover the mud or concrete floors of houses. Most homes, even in some parts of urban areas, are still thatched with sedges, although there is increasing use of corrugated iron, especially in the richer coffee-growing areas such as Jimma. Collecting of other products apart from water and sedges also occurs in the study area with natural wetland being one source of a range of medicinal plants which are universally used in this area, as well as source of craft materials.

In both cases skilled minorities collect the products, but the final item – medicine or baskets, are universally used. More transformational and potentially damaging use of wetlands is restricted to smaller groups of the population, those who own cattle or have the resources to use wetlands.

Such analysis of who uses wetlands helps identify who are the major beneficiaries, their socio-economic status, and the potential for conflicts between different users. Table 2 shows that it is men who are the main users of wetlands, with the exception of water collection by women. Hence, as wetland transformation occurs through cultivation, and wetland fringe springs dry up there are potential conflicts between men and women as the latter find they have to walk further to obtain water, or have to use less pure stream water. Similarly, there are potential conflicts between the richer farmers developing the wetlands for cultivation or using them for grazing and the poorer men who are involved with collecting wetland products. It is only a few poor men who are engaged as wage labourers or share croppers by wetland farmers who gain from wetland transformation for cropping. In general, wetlands play more a important role for rich and middle income groups than for the poor.

A further point to be noted is that as wetland cultivation intensifies with multiple cropping of tef or vegetables before maize, the drainage of these areas is for longer periods. This leads to more complete transformation of the wetlands, with less natural vegetation, much less water storage, greater alteration of downstream flows and more intense local impacts, both on wetland edge springs and on the vegetation on the lower slopes of the uplands adjoining the wetlands. This intensifies the conflict between male farmers and women water collectors and between collectors and cultivators.

Benefits	**Users /Gender**	**Collectors / Status**	**Overall Beneficiaries**	**Wider Impacts**
Water	Women	All, except rich	All	Health
Reeds	Men	Often poor	All for roofing, especially women for mat making	Shelter, supplementary income
Agriculture	Men	Mid-rich, non-aged	All through sales	Domestic and wider food security
	Men	Poor share-cropping	Poor households	Food for survival
Medicinal	Men	Skilled	All, especially poor	Health
Grazing	Men	Richer	Households with cattle	Facilitates wealth accumulation
Palm fronds	Men	Often poor	All, especially poor women	Supplementary income
Brick making	Men	Very rich	Rich and poor daily labourers	Contributes to shelter for rich

Table 2. Use Benefits from Wetlands and Beneficiaries in South-west Ethiopia.

6. Wetlands and Food Security

A recent assessment of the role of wetlands throughout much of the study area [8, 9, 11, 12] has shown that wetlands play a critical role in food security; 33% to 70% of wetland is under cultivation. The seasonal calendar shows how it affects food security, and who benefits most from wetlands [6]: the normal maize harvest from wetland is in June to August, just as the “hungry” season sets in, while the cultivation of wetland maize can be adjusted to serve the November harvest shortage.

7. Local Knowledge and the Potential for Sustainable Use

7.1. DEGRADATION IS OCCURRING – EVIDENCE EX ALAN

Despite the general intensification in wetland use in the south-west highlands in recent years, there is evidence of both the sustainable use of these areas, as well severe degradation of them [1]. Research findings suggest that degradation of wetlands is not only, or necessarily, linked to increasing intensity of use. Other factors such as catchment land use, wetland soil depth, and local geomorphological features strongly influence the eco-hydrological characteristics of each wetland, and hence their capacity to support different forms of wetland use [3, 1].

7.2. SOME EVIDENCE OF SUSTAINABLE USE REGIMES

The long history of wetland use has led to a considerable body of local knowledge which contributes towards the sustainable use of these areas [1, 2, 3]. The local knowledge and experience of farmers and wetland communities is critical in determining whether there is sustainable or unsustainable wetland use. For example, one wetland in Illubabor Zone, which has been drained and cultivated each year for over 80 years, shows little sign of environmental degradation. Discussions with farmers at this site revealed that a well developed local wetland knowledge system exists through which farmers have accumulated and developed an extensive repertoire of wetland management techniques, adapted to their local conditions. Critically, co-operation among the wetland farming community was found to be high – an important prerequisite for the labour intensive tasks involved in wetland cultivation and water management, while some by-laws had been developed to prevent the over-drainage, limit cattle grazing and to protect some areas of ‘cheffe’.

Farmers recognise that flooding is the key to wetland sustainability as it helps maintain soil fertility and controls the degradation processes associated with drainage. They employ a system of channel blocking to prevent over-drainage and once the crop is harvested to assist with flooding which helps the decomposition of crop residues, control weeds and aids the recovery of the sedge vegetation. Blocking drains is also a recognised way of retaining catchment sediment eroded during the rains, which is an important means of restoring wetland soil fertility [1, 3].

When wetland agriculture suffers from declining yields, farmers will abandon cultivation and block the drainage channels, leaving the area fallow for several years. Their understanding is that the re-establishment of the natural swamp vegetation will help rejuvenate soil fertility, the quality of the *cheffe* being seen as an indicator of the recovery process. The farmers use soil colour, soil texture and plant indicators to identify wetlands which will be suitable for drainage and cultivation in terms of fertility, moisture storage and ease of drainage [1].

Hydrological knowledge amongst wetland cultivators is very detailed. They adjust the depth and density of drains, and their layout, in response to variations in water and soil conditions in different parts of the wetlands.

Farmers also realise the importance of maintaining ‘cheffe’ at the head and outlet of a wetland to retain water and prevent down-cutting.

7.3. EVIDENCE THAT PRESSURE LEADING TO NEGLECT OF PRINCIPLES

However, local wetland knowledge is not always adequate to ensure sustainable use and in some sites there has been over-drainage leading to the abandonment of cultivation and wetland product collection. This sort of problem may sometimes be the result of a lack of adaptation of local knowledge to different sites, to larger areas of drainage, and to different labour resource situations. Possessing the capacity to address and adapt local knowledge to new environmental and socio-economic circumstances may be a problem, especially if farmers are restricted by time and resources in their acquisition, or development, of new wetland knowledge and skills. In wetlands where drainage and cultivation has a short history, and particularly where wetland cultivation has been imposed suddenly upon a community, degradation is a common phenomenon. This is arguably because wetland use under these circumstances does not build upon, develop, or incorporate indigenous practices and local knowledge [7, 1, 3]. Wetland degradation also occurs where there are strong economic or political pressures that lead to the complete drainage of the wetland and sometimes the adoption of double cropping. This is often associated with the development of market opportunities or with the enforced cultivation in response to the government concerns for food security. Lack of local institutional capacity seems to be another regular problem, for instance where there are not adequate arrangements for controlling and co-ordinating the use of wetlands.

7.4. COMMUNITIES NEED ORGANISATION

Some indigenous institutions have been developed to support the application of this local knowledge. In the traditional system of community administration developed by the Oromo of this area, one of the community elders was appointed as an Abba Laga, or “father of the water”. This person was traditionally responsible for co-ordinating the use of the wetlands for a variety of purposes including drainage agriculture. Elements of this system continue today with communities developing by-laws relating to wetland use, often limiting drainage in order to protect other wetland resources [1].

8. Conclusions

The main conclusion is that economic pressures influence how wetlands are used and how they provide environmental functions. Therefore, to achieve sound environmental management, there is a need to recognise the economic role that wetlands play in headwaters. An integrated approach to land use, economy, ecology, and cultural context is needed that is sensitive to local knowledge, institutions and gender and poverty issues. There is a need to consider the role of the wetland catchment as well as its downstream effects.

This said, the importance of wetland varies around the region. Wetland is the main agricultural resource in parts of Wollega, where the interfluves are degraded, but it is more commonly used for grazing in the Jimma Zone where it appears that over-drainage has facilitated the use of these areas by cattle. In other places, the wetlands are used as supplementary sources of food, with maize grown in Illubabor and coco yams grown in Keficho [1], [2].

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THE LAKE KINNERET DRAINAGE BASIN:

Headwater Discharges, Hydrology and Nutrient Dynamics in the Hula Valley Wetland

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KEYWORDS / ABSTRACT: Wetlands /, Hula valley / water management / water pollution / Israel

The “Hula Project” is a constructed wetland ecosystem in northern Israel up stream of Lake Kinneret. The water budget of this lake Kinneret is controlled by precipitation and human management, especially the regulation at South Dam and the National Water Carrier. Effective management depends on successful collaboration between stakeholders. Currently, this partnership operates successfully, which has positive benefits for the future prospects and general sustainability of the system.

1. Introduction

The “Hula Project” is a constructed wetland ecosystem in northern Israel (Figure 1). It includes areas of natural and introduced vegetation, agriculture, the shallow Lake Agmon and a system of drainage channels. The management of this multifunctional wetland, which has important roles in water supply, agricultural production, ecological conservation and also the tourist industry, depends upon defining efficient synergies between farming, nature preservation and water quality protection.

J. Krecek and M. Haigh (eds.),
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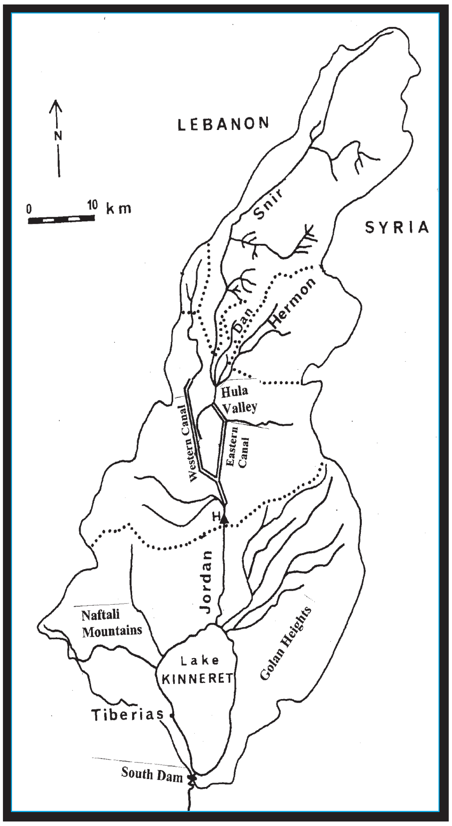

Figure 1. Hula Valley, northern Israel.

Management of the water regime is critical because these waters must satisfy both local needs for irrigation and the conservation of the fragile peat soils and also contribute to the national water budget, where there is general concern for water supply and the protection of water quality. Effective management depends on successful collaboration between stakeholders. Currently, this partnership operates successfully, which has positive benefits for the future prospects and general sustainability of the system.

2. Lake Agmon Water Chemistry

Nutrient	**Mass balance (Inputs minus outputs, $t.a^{-1}$)**	**Nutrient outflow ($t.a^{-1}$)**
Ammonium	+15.5	1.3
Sulphate	+268.2	885.0
Nitrate	+14.6	1.04
Total Nitrogen	+35.0	12.0
Total Phosphorous	+0.7	0.9

Table 1. Mass balance and nutrient discharges from Lake Agmon (2001).

Table 1 displays the mass balance of Lake Agmon and shows it to be a major sink for pollutants. The Lake encourages N removal through denitrification and sedimentation but phosphorus is also enhanced through plant mediated P and bird excretion. Lake Agmon's role in the mitigation of pollution by these nutrients could be increased by water diversion and (probably) the mechanical removal of aquatic vegetation. This said, the system faces several challenges. These include: significant water losses between the headwaters and Huri Bridge during droughts (Figure 1 - H at the southern end of the Hula Valley). There are also intensive underground water fluxes through preferential flows in the Hula Valley.

3. Lake Kinneret

In Lake Kinneret, limnological processes are dominated by regional natural sub-tropical conditions. However, multi-annual trends indicate the decline of TP, TDP and increase of particulate P; longer residence times, lower water levels, and declining inputs of discharge. Zooplankton populations are not limited by food supply but are strongly affected by fish predation. Salt concentrations are mostly affected by dilution but the total load is enhanced by discharge increase.

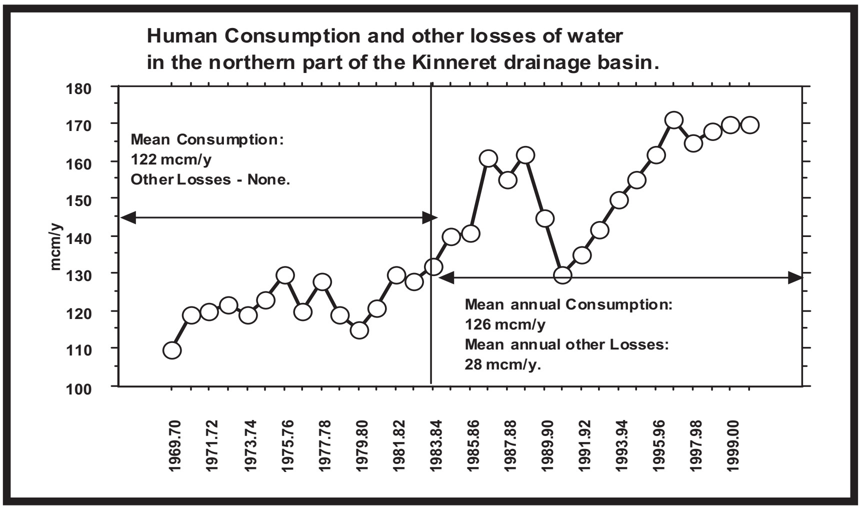

Figure 2. Water losses in the Lake Kinneret headwaters.

Overall, the water budget of Lake Kinneret is controlled by precipitation and man made operations, especially the regulation at South Dam and the National Water Carrier.

ENVIRONMENTAL CHANGE IN HEADWATER PEAT WETLANDS, UK

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KEYWORDS/ABSTRACT: Uplands / peat lands / hydrological role / hydrochemistry / over-grazing / burning / drainage / forestation / pollution / reclamation

Around 13% of the UK is peat wetland. The perceived value of this land has been low and much has been invested in converting these lands to agriculture and forestry. Perhaps a fifth of the British peaty uplands have been drained and, since 1945, about a fifteenth forested. The traditional view is peat lands adsorb and store rainwater but undisturbed peat wetlands are poor aquifers and act mainly as surface flow systems that do little to moderate floods. By contrast, after drainage, peat land may do more to moderate flood flow because of increased soil storage. However, drainage ditches increase the speed of runoff and encourage erosion. Overgrazing, trampling and burning also encourage accelerated runoff and erosion. Hill farming fosters pollution through the release of organophosphate sheep dip, fertiliser and pesticides, including the Asulam used to control bracken. Peat headwaters produce storm runoff that is acidic but drainage increases the chemical loading of most ions and reduces the pH. Burning moderates pH but forestation encourages acidification. Peat bogs are net sinks for CO_2, N and many other environmental chemicals but environmental change may reverse this effect. By contrast, disturbed soils are sinks for methane while undrained peat lands are sources. Better environmental management understanding is required to maximise the benefits to stakeholders of the UKs upland wetlands and to minimise potential negative impacts due to climatic emissions of greenhouse gases, hydrological changes especially flooding, water chemistry, and sediment release. There remains a need to assess their continuing role in current and future land use systems, especially hill farming, forestry, water resource management, forestry, tourism, and nature conservation. Current research evidence is ambiguous but the present presumption favours preserving Britain's peat wetlands and some investment in the restoration of the most degraded areas, especially those used for tourism or nature conservation.

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 237–255.

1. Introduction

Nationally, headwater hill lands occupy around 7.5*10^6 ha of the UK land surface. About 2.9*10^6 ha (13%) is underlain by peat that is at least 50% organic and at least 30cm deep [1, cf. 2: 1.64*10^6 ha). Most (90%) of the UK's peat-land is found in Scotland [3]. Much of this terrain is dominated by Ling (*Calluna vulgaris*) and other shruby heaths, and blanket bog. Blanket bog is a special aspect of the UK's peat land. The UK's peat lands may represent less than 1% of those in the whole northern boreal and subarctic zones but its area includes between 7 and 15% of global blanket bog [1], [3], [4], [5]. Peaty soils cover the bulk of the UK's upland headwaters. Britain may have around 6.1*10^6 ha of shallow peaty soils and, outside the Somerset Levels and Fens of East Anglia, most are located in the uplands. Typically, these soils are stagnohumic gleys, peats and, where the drainage is slightly better, peaty podsols [6]. Such soils are famously variable over short distances and show great sensitivity to small changes in soil texture, consolidation, or drainage [7].

Most of the UK's peaty uplands have been degraded by human activity. Today, only a tiny fraction of Britain's original peat wetlands survive - around 10% of the blanket bog and 2% of its raised mires, 125*10^3 ha and 450 ha, respectively [8]. There are no figures for the destruction of the thinner peat soils. However, the condition of most soil profiles in the Welsh uplands has long been described as 'truncated' because of the loss of the surface horizons [7, 9]. This paper examines the causes and consequences of the destructive contemporary environmental changes that affect the UK's peaty headwaters.

2. Environmental Change in UK Peatlands: Human Impacts

Today, many development processes drive environmental change in the UK's peat land. These include the long term impacts of activities that include overgrazing and burning, forestation, especially of the shallower peat soils, and drainage - both deliberate and inadvertent; legacies from activities that were severe in the past but are now largely controlled, such as peat extraction and, to some extent, air pollution; and a wide range of new impacts whose effects are increasing. Some are the consequent upon changes in farming practices, which have encouraged ecological changes such as natural succession to scrub and invasion by species such as bracken (*Pteridium aquilinum*). Others are due to economic developments, which include road construction, the development of infrastructure associated with wind farms, telecommunications, water supply and energy, and the impacts of a booming tourist industry. This has brought increased recreational disturbance through trampling and trafficking involving bikes and off-road vehicles as well as side effects including uncontrolled fires. Finally, there are the impacts of anthropogenic climatic change – global warming [5].

Long term and recent over-grazing by sheep and other livestock is considered a major cause of peat land degradation. The symptoms of overgrazing are widespread. Overgrazed heather plants are reduced to small dome-shaped clumps in mainly grassy areas, while there are large areas of exposed peat, tracks and standing water. As a consequence, erosion and suspended sediment yield increase. Sheep are blamed for up to 5,000 ha of eroded peat land in the Peak District of England [10]. In the England's North Peak Environmentally Sensitive Area (ESA) the "Great Fence of Bleaklow", a 10-year temporary construction that encloses about 2,500ha, aims to exclude sheep so that plants may recolonise severely eroded areas that are currently just bare peat [11].

In the case of Wales, the uplands support most of the national flock. In 1999, this amounted to some $11.5*10^6$ (1999, cf $10.8*10^6$ in 1988, $6.0*10^6$ in 1971) sheep, about 26% of the EU flock, and around 4 times the human population of Wales [12]. Over much of upland Wales, the maximum sustainable stocking rate between March and October may be just one sheep per hectare, while actual stocking rates in 1999 were around 7 per hectare. Of course, at the time, the economics of sheep farming in Britain were driven by EU subsidies. These were awarded per animal and, in the late 1990s, these far exceed the market value of the animals or their products – sometimes by a factor of 5 or more. This encouraged much overstocking, which ended abruptly with an outbreak of Foot and Mouth Disease, a disaster for a farming community where 94% of farms depended on livestock. Disease control led to the slaughter of 6,250,000 animals across the UK. Subsequent UK government reports suggest that the effects of this cull were short-term and local: restricted to some pollution from disposal sites and some water pollution from disinfectant runoff in 2001 [13]. However, grazing pressure was abated for one or two years.

Contemporary EU moves to shift the basis of grants from livestock numbers to area managed, aimed to reduce stocking density to 0.2 - 0.15 livestock units per ha with penalties levied against higher stocking rates, could help prevent a recurrence of the excesses of the 1990s. Today, the poor economic foundations of hill farming and the changing structure of agricultural subsidies are leading to farm abandonment and the conversion of farms to other uses, often tourism [14]. This may lead to improvements, especially in nature conservation terms, for peat land and wetland areas [11].

However, erosion of peat lands can still occur even at reduced stocking rates. Higher stocking densities have to be sustained by winter feeding. Livestock linger near feeding points causing both overgrazing and increased soil fertility – both of which encourage plants other than the moorland heaths. Official guidelines commend the movement and dispersion of feeding sites and ask that feeders avoid recently burned or fragile heather areas, where the plants are other than 15-30cm tall. However, this is not always feasible.

Of course, grazing is not the only problem caused by sheep farming. In Wales, pollution caused by the organophosphates used in sheep dip affects 75% of the sampling sites in sheep rearing areas, perhaps 1,200 km of stream course, approximately 10% of the national length of polluted watercourse. In sheep rearing areas, 75% of streams were polluted [15]. Similarly, waste from winter feeding, applications of lime and fertiliser, often applied to improve pasture, and pesticides all lead to a decline in heather cover and may cause increased chemical release in runoff.

Bracken (*Pteridium aquilinum*) has spread massively in during recent years and is a problem for most British peat lands [16], [17]. In former times, bracken was actively controlled but for more than a century it has been allowed to spread. Data from the North York Moors (1986) suggested that bracken dominated around $12*10^3$ ha of moorland and was spreading at 1% per annum, while figures of 4% p.a. were current in Wales [18]. Bracken contributes to overgrazing and land degradation indirectly. Its shade and litter smother fodder grasses and herbs and so reduces the availability of pasture on the better soils and encourages more grazing of peat lands. In late summer and autumn, bracken fronds can be a significant fire hazard. Bracken spores are carcinogens in humans and the plant is toxic to livestock, but cattle consume young bracken and trample down more than they eat. The replacement of cattle by sheep on hill pastures has been a factor in bracken's spread. Its invasion of peat lands is also linked to soil improvement and drainage.

Bracken eradication techniques include herbicide use and mechanical removal. The selective herbicide, Asulam, is sprayed in July and August, often by aerial application. There is concern about the amount of this herbicide that enters watercourses and wetlands. This method of control is now discouraged. In any case, the removal of dense bracken stands leads to exposed soils, increased storm run off and an increased pH. Bracken is not the only serious ecological invader of disturbed peat lands. As the lands dry out, or as management regimes change, the peat land may become invaded by scrub such as birch, rowan and gorse, which is also a fire risk. To preserve the heather and wetland plant communities, conservationists resort to cutting and more herbicide treatment.

For many years, most especially during the Nineteenth Century, many moor lands were valued as hunting preserves, grouse moors. These were maintained and expanded by management that involved regular burning. The most effective way of maximising the stock of game birds was through controlled burning, which encourages the moorland shrubs to produce new shoots. Research by the Game Conservancy has indicated that moorland drainage also improves heather growth but only over a very limited area [19].

Burning, when carried out correctly, can be a valuable tool in the regeneration and management of heather moorland. Unfortunately, badly executed, accidental or malicious burning, which has become common with the development of tourism and increased road access, causes major damage. In the English Peak District (1970-1975), >300 moorland wild fires were recorded. These affected about 8% of the total moorland area [10]. Land degradation varies with the severity of the burn. If the fire moves quickly, rootstocks may escape damage and plants recover swiftly but slow moving burns can kill rootstocks and even ignite the peat. Such fires may burn for weeks [20].

Today, the tourist industry is a major threat to the peat lands both indirectly, through the creation of infrastructure, and directly through trafficking and fire-setting. In Wales, many hill farms seek to supplement their income by engagement in the £1.9 billion tourist industry. Meanwhile, trampling damages caused by recreational hikers and mountain bikers is locally important and increasing. In south east Lancashire, the degradation of moorland landscapes is attributed largely to their proximity to urban areas and the pressures of informal recreational usage [11].

Since 1945, around $190*10^3$ ha of deep peat land, and a further $315*10^3$ ha of the UK's shallow peat land, has been forested with commercial conifers [21]. In Scotland, most new planting (ca. 72%) has taken place on soils with deep surface organic horizons [22]. Originally, conifer plantations were promoted as an economic crop with benefits to the prevention of water pollution by livestock and humans [23]. For many years, it was agreed that forestry was the most economic use for many peat wetlands and many thousand of hectares were planted. The current mainland UK forest area of $2.7*10^6$ ha includes $1.6*10^6$ ha under conifers, much of this in the upland [24]. In Wales, the area of forest doubled in the 30 years to 1985, but it has remained more or less constant since [25]. Today, forestry is regarded as uneconomic on most types of moorland, the soils are too poor and growth rates too slow, and most official grant support is discontinued. In the mainland UK, rates of replanting have dropped from >$40*10^3$ ha.yr^{-1} to <$14*10^3$ ha.yr^{-1} (2002-2004) [24].

Until quite recently, British governments encouraged land 'improvement' by drainage. Around $1.5*10^6$ ha of upland Britain has been drained [6]. In lowland agriculture, drainage was mainly achieved by the laying of pipes but, in the uplands, the favoured technique was 'gripping'. Gripping involved cutting <0.5m deep drainage ditches at 15 - 35m. intervals. The characteristic herringbone pattern of these grips is to be found on many peat uplands.

For many years, peat was mined, first for fuel and later for garden compost. In the 1990s, proposals to ban peat extraction were staved off by Government research that showed a unilateral ban would damage the nation's horticulture industry [2]. By 2002, only 6,000 ha were being used by the industry and this area is declining [2]. In March 2002, the UK Government announced plans to discontinue peat extraction on three major peat land areas, a total of 1658 ha (Wedholme Flow, Cumbria, Thorne and Hatfield moors in South Yorkshire), paying £17.3 million in compensation. Today, peat extraction for fuel and garden fertiliser has almost disappeared from the UK, outside Scotland's Isle of Skye, Sutherland and Caithness [1].

Meanwhile, the industry is being encouraged to develop substitute products. The need for energy also provides some of the most controversial causes of peat land destruction in the present day. Large tracts of peat land have been destroyed by the mining of coal. Wales' official statistics identify $17*10^3$ ha of derelict land, much of it in this category, but the total may exclude land used for surface mining [25]. More topically, throughout upland Britain, proposals are going ahead for the creation of wind farms. Whatever the scenic or sonic impacts, the major problem is due to the construction of infrastructure and the access roads needed for servicing and construction. This disturbance is graphically illustrated by the website for the campaign against the Cefn Croes Windfarm [26]. Similar disruption is caused by the construction of communication masts and pipelines. Meanwhile, the UK's formal road network has increased from < $300*10^3$km in 1953 to $392*10^3$ km in 2003 and it is likely that the UK's peat lands have seen a similar proportional increase [27].

The EU Habitat Directive describes the many threats to the security of Britain's peat land: drainage and water abstraction, forestation, deforestation, fertilisation – also liming, pesticide use and overfeeding of grazing animals, overgrazing, trampling, uncontrolled burning, natural succession and the introduction/invasion of non-native species – notably bracken and scrub invasion. It also mentions peat extraction, road construction, mining and other types of development. Among these latest threats to these upland areas are wind farms and microwave telecommunications masts, or rather their associated infrastructural constructions of tracks and service access-ways.

3. Hydrological Effects of Environment Change in Headwater Peat Lands

Peaty soils dominate the upland moorland headwaters in the UK. Inevitably, by virtue of their great extent, they have an important role in the environmental and hydrological performance of British headwater regions. Environmental changes caused by human activities have altered the characteristics of these areas and these processes continue into the present day. Inevitably, headwater changes will have impacts downstream. The question that remains open is how great are these impacts and how widespread?

Unfortunately, 'a gulf' remains between the practical concerns of environmental managers and the research interests of most academic environmental scientists [28]. There is a scarcity of published work that integrates the wider concerns of environmental managers with academic research into the hydrological and hydrochemical functioning of catchments at different scales [28]. Hydrological processes are thought to span about 8 orders of magnitude [29]. Recent increased awareness of scale issues in hydrology is attributed to 'increased environmental awareness' [30]. Meanwhile, Soulsby et alia's [28] studies of sub-catchments of the Scottish River Dee found that the blanket peat wetlands that dominated the headwaters also dominate the storm response, generating runoff by saturated overland flow. However, as the basin was examined at progressively larger scales, so the importance of these plateau peat lands diminished.

Upland wetlands are lands that are periodically or seasonally saturated or inundated by surface or ground water on an annual or seasonal basis and that display hydric soils. Typically, they support hydrophytic vegetation above a perched water table [31]. Often, their hydrological attributes have commanded pride of place in lists of functions and values [32]. Conventionally, peat hydrology is controlled by: depth of organic peat layer, depth of the water table, temperature – evaporation & transpiration and the impacts of human disturbance. Blanket peat has 3 layers: acrotelm, catotelm and a transitional layer [33]. The acrotelm lies above the average water table (although it is periodically saturated) and within it aeration triggers active decomposition (humification). This layer is periodically permeable and generates near surface runoff, which may cause peat erosion - especially when the peat is dry and loose. Below is the catotelm, a saturated layer. Here, peat accumulates because there is little water movement, no oxygen, hence little organic decomposition. For the model to manifest, the water table must remain high enough to allow the catotelm space to accumulate dead plant material and retreat low enough to allow aeration and humification in the acrotelm. Since the boundary is deeper in dry weather and years and higher in wet periods, it is possible to recognise a transitional layer between the two [5, 33]. The model has been criticised because it is two dimensional and ignores the important role of macropores and soil pipes in peat land hydrology [34].

The traditional view of peat moorland is that it acts like a sponge; its organic fibres soak up rainwater and release it slowly to both groundwater and surface runoff [35]. Peat soils have much higher (5-7 times) hydroscopicity than mineral soils and field measurements of peat find their gravimetric water content runs upwards from 86 to 94% and peat can retain up to 25 times its own weight of water [36]. So, when less than saturated, such soils have a great capacity to absorb and hold rainwater. According to Black [31], bogs and fens typically exhibit "low net horizontal movement in relation to rather high net vertical movement". However, capillary rise in peat soils does not usually exceed 1200-1500mm [36]. Most peat lands are wet because they are poor aquifers and remain wet because of poor drainage or inputs from groundwater [35]. Studies of undisturbed peat show that that very little runoff is produced from the peat matrix. Instead, most runoff forms as saturation excess overland flow and near surface through-flow [34]. In degraded and eroded peat on steeper slopes, the bulk of flow may be transmitted through large soil pipe systems [37]. In the northern Pennines, 81.5% of overland and matrix through flow from three study catchments came from the peat surface, 17.7% from the 0-50mm layer and less than 0.1% from depths greater than 100mm [38]. Holden and Burt [34, 38] argue that because upland blanket peats are surface and near-surface flow systems, they respond very quickly to rainfall (2.1-3.2 hours mean rainfall to peak in basins of 1,140 ha, 83 ha, and 44 ha respectively) and so tend to be sources of flooding rather than attenuators of flow.

Artificial drainage has important impacts on the hydrological behaviour of peat land. Drainage affects evapotransporation, which increases in dry conditions. Undisturbed peat lands in Canada yield evapotranspiration at levels between 17-76% of the potential maximum [39]. In Russia, the ratio of evapotranspiration from bogs and drained land varies from 1:1 in the southwest to 1.2-1.6 in the north. Here, drainage both reduces evapotranspiration and increases runoff by a factor of 1.3 – 1.5 [33]. After intense desiccation, much peat loses its capacity to absorb water and swell because its fibres become coated with hydrophobic resins [36]. However, when peat lands are more gently dewatered by drainage, the changes are slow. Eventually, the soils decompose, lose their ability to hold moisture, subside - perhaps as much as 100-150mm per metre of peat deposit, and increase in dry bulk density. Ultimately, the colloids of the soil coagulate and, commonly, fissures form, through which water can move rapidly [36]. Any temporary increase in water storage capacity, caused by dewatering, is lost and, in affected catchments, the hydrographs may begin to register higher peaks and steeper limbs [1].

The drainage of peat lands is, therefore, often linked in the media to increased flooding in UK rivers [40]. Cutting ditches improves the efficiency of the drainage network. Several studies link drainage to increased peak flows and erosion [1, 41, 42]. Equally, cutting drainage grips should draw down the water table and create a larger drained zone, perhaps 0.2m deep in winter and 0.45m deep in summer. Canadian studies show that depth to the water table increases with the spacing of ditches and varies with the depth of the peat layer [43]. Drainage increases the duration of runoff and reduces peak flows, up to the limits of the storage volume, hence, perhaps not affecting the largest floods [44]. The balance of evidence suggests that peatland catchments that are drained by ditches (“gripping”) exhibit increases in low flows and in flow duration [45]. However, drainage both reduces peak flows by increasing the volume of soil available for soil water storage and increases peak flows by improving the efficiency of drainage.

Faster runoff in grip channels can cause erosion and many become severely incised. These larger channels further accelerate the drainage of the peat and the speed of discharge to local streams, where the increased flashiness may allow greater bank erosion. Universally, ditching exposes soils and channels flow so allowing increased erosion and sediment transport. The legacy of moorland ‘gripping’ continues on many peat areas, with erosion of the peat causing loss of vegetation and silt deposition downstream.

Moorland burning also impacts on catchment hydrology. Fire can have major impacts on peat land promoting losses of nutrients both to the atmosphere (carbon, nitrogen and sulphur) and runoff. In shallow peaty soil and the areas surrounding peat land, hydraulic conductivity may be reduced by fine ash particles, so clogging up soil pores, hence increasing runoff [46]. Dried and burnt over peat is easily eroded and contributes to sediment pollution in streams and reservoirs. After a burn, peat may become desiccated and more acidic – especially if the local rainfall is acidic as in the southern Pennine Hills, where pH may sink as low as 2.8. Drinking water supplies may become brown-coloured due to the aerobic bacterial activity in the peat following a fire, so requiring expensive treatment [20]. Finally, the restoration of burnt peat land often involves fencing out sheep to allow regrowth but this is expensive and unpopular in the community.

Forestation also has important hydrological impacts on peat lands. Trees have large and extensive root systems and a high water demand, especially when becoming established. Foresters talk of the ‘watering up’ of peat lands following forest cutting, which is the result of reduced evapotranspiration. Simultaneously, runoff may increase by 40% [47]. The converse, forestation dries up peat soils causing them to compact, crack and degrade [5]. As early as 1956, Law [48] had reported a 280mm net loss of runoff from a 450m^2 plot converted from grassland to spruce, a pattern subsequently verified across the country and beyond. Conifers need a root system deep enough for them withstand wind throw. Ground preparation often involves deep ripping to destroy iron pan layers and gripping with drainage ditches. Ditching ahead of planting has caused increased flood peaks, which decrease after canopy closure. It also causes increased sediment export to levels 2-5 times greater than that from undisturbed grassland [49]. At the end of the production cycle, harvesting is often accompanied by a surge of sediment release.

Many other types of development affect upland peat lands in the UK. In general, road construction, construction and mining all lead to large initial increases in runoff and sediment yield. Kilmartin [50] has shown that runoff from surface coal-land reclaimed as pasture in Wales may be flashier than that from degraded peat lands but the sediment release from a mature and densely vegetated site may be lower. In general, development includes the expansion of armoured surfaces and drains, which accelerates runoff, and also increases the release of pollutants into water courses.

4. Hydrochemical Effects of Environment Change in Headwater Peat Lands

The drainage of peat lands causes an increase in the availability of many soil nutrients and consequent increased release of almost all major ions, including metals (Al, Fe,Cu, Mn), amonium, and Phosphorous. It increases runoff colour, temperature, conductivity, suspended load, conductivity and soil pH; one Scottish result reports a rise from 4.4-5.4 following drainage [1, 43]. The new major review by Holden et al. [1] adds that drainage may increase nitrate release, and the loss of Ca, Mg and K but decrease total organic C (TOC), dissolved organic C (DOC) and dissolved organic nitrogen (DON). Wetland drainage increases rates of sulphur oxidation and organic decomposition leading to the release of organic acids as well as sulphate, the nitrogen compounds like ammonium and nitrate, phosphorus and potassium [51, 52, 53, 54].

Conifer plantations, which transfer nutrients from the soil into undecomposed surface litter, encourage soil acidification. More acidity comes from atmospheric pollutants that are trapped on the tree needles. UK sulphur dioxide emissions halved between 1980 and 1995 but deposition rates remain high. In the Pennines, deposition rates for sulphur and nitrogen (1992-94) were 30 $kg.S.ha.yr^{-1}$, total N deposition 18-30 $kg.N.ha.yr^{-1}$. Upland Wales recorded 15-30 $kg.S.ha.yr^{-1}$ and 16-24 $kg.N.ha.yr^{-1}$ (1992-1994), albeit partly because of high rainfall. Perhaps a third of Wales' soils are affected by acidic deposition and about 50% of rivers [55].

Increased acidity may cause increased leaching of calcium and magnesium from nutrient-rich peat or aluminium from nutrient-poor acid peat. Peat headwaters of the Scottish River Dee produced storm runoff that was acidic and enriched in TOC [28]. In practice, these effects may be countered by agricultural liming [54]. The ash left after moorland burning may also buffer acid release in runoff. Ultimately, most of the base cations from the burnt vegetation are converted into soluble salts and leached into the underlying soil, so resulting in increased soil pH [54].

5. Climatological Effects of Environmental Change in Peat Lands

The drainage and loss of headwater peat lands has serious implications for the role these lands can play in global climatic change [5]. Carbon dioxide (CO_2) was estimated to comprise 84% of the total global warming potential of UK gas emissions in the year 2000 [56]. Soils and litter represent the largest carbon pools in the U.K. estimated at 10,000 TgC and as much as half of this is peat [57]. Upland peat soils in Wales are estimated to contain a mean value of 250 MgC.ha in their upper 150mm compared to only 20 MgC.ha for the same depth of agricultural soils. Normally, these soils allow very slow rates of carbon turnover, which is why soil accumulation is a valued means of carbon sequestration [56].

Carbon sequestration in northern peat land has been estimated at 0.2-0.5 $MgC.ha.a^{-1}$ [21, 58] and measured as 0.22 and 0.25 $MgC.ha.a^{-1}$ on undisturbed peat at two Scottish sites [59]. The decomposition of carbon from decaying organic matter is severely delayed under the anaerobic conditions of poorly drained or waterlogged peat soils. Most peat bogs are net sinks for CO_2 and many other environmental chemicals. However, environmental changes including drainage and forestation can affect sequestration, indeed disturbed peat soils tend to become net carbon sources. Drainage of peat reduces the anaerobic zone, so drained and recently forested peat wetlands can exhibit substantial and extended carbon dioxide release (>0.3 $MgC.ha.a^{-1}$) on afforested peat after 26 years) [60 and Table 1]. The UK's Forestry Commission has published guidance on how to identify peat bogs where tree planting should be avoided and how to assess the potential environmental gains from restoring bogs already converted to woodland [61].

Soil Type	Grassland	Forest	Change
Peat	1200	450	-750
Humic Gley	180-400	250-450	50-70
Podzol	200-400	250-450	50
Humic stagno podzol	180-400	250-450	50-70
Stagnogley	170-400	170-450	0-50

Table 1. Typical soil carbon storage levels for peaty soils and projected changes following forestation (MgC.ha) [63].

Peat extraction for horticulture is said to add round 0.06% of UK total greenhouse gas emissions [2]. However, $3.4*10^6 m^3$ are consumed each year in horticulture and amateur gardening. Carbon losses are also caused by burning, overgrazing and erosion, which is widespread in upland headwater peat lands [5, 62]. Additionally, since peat bogs lose their capacity to sequester carbon in warm years, global warming may raise local temperatures sufficiently by 2021 for most UK peat lands to become net carbon sources [60].

Drained peat soils tend to undergo denitrification, which releases both nitrogen and N_2O to the atmosphere. As a greenhouse gas, N_2O, which makes up about 80% of the nitrogen release, is >300 times more powerful than CO_2 [64]. Undisturbed peat lands may be net sinks for nitrogen but, after drainage lowers the water table, microbial activity increases. This dramatically accelerates N_2O emission rates. N_2O emissions from UK upland peaty soil may rise to as much as 0.1 to 0.5 $kgN.ha^{-1}a^{-1}$ [65]. Ultimately, the gaseous emissions from the drained soils decline as the soil becomes better aerated. Nitrogen mineralisation rates are inhibited by low pH and also nutritional constraints in the organic matter [1]. Of course, peat bogs famously emit methane, which is another greenhouse gas. Methane emission from UK peatlands may be 18 $kt.C.a^{-1}$ [66]. The main source of methane is intense bacterial production just below the water table but some of the methane produced is oxidized to CO_2 before it reaches the atmosphere [67]. The drainage of peat land, either for agriculture or forestry, tends to converts the land into a net sink for methane [68].

Improving drainage increases the acidity of through-flow. When saturated, peat moor-lands act as sinks for atmospheric nitrogen and sulphate but this is released when they are drained and the soils become aerobic. Studies in the Yorkshire River Nidd have shown that when drainage is reversed pH levels rise and leading to improved fish stocks downstream.

6. Reclamation of Peatlands

The above emphasises that peat wetlands play an ambiguous environmental role in upland Britain and that they have, in the past, mainly been valued for their capacity to be transformed into another more productive land-use type. However, in recent years, official perceptions have changed. Currently, around $200*10^3$ha are protected and attention to restoration has overtaken the clamour for land improvement by drainage [2]. For example in Cumbria and Northumberland, where many bogs have drained for agriculture or forestry, an EU LIFE project, "The Border Mires Active Blanket Bog Rehabilitation Project" works to reverse these effects [69, 70]. To date, around 150 ha of conifers have been cleared, 2,500 dams installed to block drainage ditches and 100 shallow pools created. In many cases, these concerns reflect an interest in the special habitats provided by these upland wetlands and the unusual species and ecological communities they support. The procedures are described in a

Government handbook [71]. However, Holden et al. [1] describe the reclamation efforts in the UK as hit and miss, *ad hoc,* affairs and, while praising the great efforts devoted to the many worthwhile projects, regret that so much is wasted because of a poor general understanding of the hydrological and environmental system. They conclude their review paper by asking the question 'restoration to what' wondering if the best plan is to try and return these wetlands to current ecological conditions or to prepare them for the future?

7. Conclusions

Upland peat lands serve a large number of environmental functions. These include: physical and hydrological influences on flood flows, sediment loads, and aquifer recharge; biochemical impacts on water qualities, and biodiversity through the special habitats they provide [32]. They also serve wider functions to the human communities of headwaters providing water, peat, timber, and grazing land. Locally, some of these lands are also valued for aesthetic, cultural, recreational and educational values – although these benefits are sometimes exaggerated [31]. Britain's NERC (Natural Environment Research Council) adds the value of preserving a record of environmental change and the sequestration of carbon, a function which is much debated [72]. Their assessment also suggests some sustainable land uses: runoff modification, controlled light grazing, forestry (where naturally forested) and human recreation.

However, the perceived value of such land is best summarised through reflection upon the huge effort that has been devoted to converting these lands to other, more valued, uses. These destructive uses have included agricultural reclamation through drainage, forestation and peat cutting, all of which have been reduced in recent years, except for continued forestation on the more shallow peats [1]. The perceived value of these lands is also qualified by the number of threats registered for those peat lands that remain, which include drainage – both deliberate and inadvertent, erosion, water pollution, mining, road construction and other development, and ecological pressures that include trampling, overgrazing, as well as transformation by ecological invasion and natural succession. Many of the latter are changes that have followed reductions in the amount of upland that has been managed by regular controlled burning [73].

Britain's Natural Environmental Research Council (NERC) recognises that wetlands are a source of public concern and they list several research priorities [72]. These begin with inventory using remote sensing and GIS, hydrology - including research both on the wetlands themselves and their role in larger catchments, the microbiology of organic matter accumulation, biodiversity, studies of the stability and resilience of wetland ecosystem functions, the restoration of damaged wetlands and interdisciplinary cooperation towards these ends [72]. Naturally, these research objectives more closely represent the self-serving wishes of the research community than the practical needs of environmental management. Here, the key issues remain the clarification of the effects of wetlands on larger catchments and in the wider environment. Better understanding is required in order to maximise the benefits of these upland wetlands for all stakeholders and to minimise potential negative impacts due to climatic emissions of greenhouse gases, hydrological changes especially flooding, water chemistry, and sediment release. There remains a need to assess their continuing role in current and future land use systems, especially hill farming, forestry, water resource management, forestry, tourism, and nature conservation. Here, current research evidence is ambiguous but the present presumption favours preserving Britain's peat wetlands rather more than their transformation to other uses. This extends to the restoration of some of these areas that have been degraded, especially in areas much used for tourism or nature conservation.

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ENVIRONMENTAL PROBLEMS OF HEADWATER WETLANDS IN HUNGARY

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In Hungary, headwater wetland habitats have received insufficient attention. This paper gives a brief account of the headwater wetlands of Hungary, their evolution, significance, usability, ecological role, functions and the requirements imposed on them. Wetland habitats sustain a large number of plant and animal species, including numerous rare and endangered ones. For nature conservation, they provide niches for endemic species. From an environmental viewpoint, headwater wetlands play an important role in reducing runoff, improving water quality, and as important landscape-ecological barriers for certain species. Wetland habitats are valuable in education and research and they can be important environmental indicators.

1. Introduction

Ever since the cyanide pollution of the Tisza River and flood events of recent years, the attention of environmental experts and hydrologists has turned toward the problems concerning lowland rivers in Hungary. Wetland habitats of international significance in Hungary are to be found without exception in flatlands, and public interest has also focused on them since the Ramsar Convention came into force. In contrast, wetland habitats in mountain and hill regions have not been considered duly, at least their problems were neither paid due attention nor were they financed properly. This study is an attempt to give a brief account of the headwater wetlands of Hungary, on their evolution, significance, usability, ecological role, functions and on the requirements imposed on them.

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Environmental Role of Wetlands in Headwaters, 257–264.

2. Characteristic headwater wetland habitats in Hungary

Headwater wetlands occur in various environments in Hungary and their extent differs widely. Their development and character chiefly depend on geological features and soil conditions of a given area, whereas size and replenishment are controlled by climatic and microclimatic circumstances of both the wider and closer surroundings.

Beside loess and loess-like deposits, mountain and hill regions are covered mainly with sandy sediments of varied grain size composition. They are overwhelmingly of Late Miocene (Pannonian) origin, and formed as littoral and shallow water sediments in the Pannonian Sea (occupying the area of what is now the Carpathian Basin) which subsequently shrunk and turned into an inland lake. Being a porous media, sand has excellent hydrological conductivity and infiltration capacity. In places where these sands are underlain by impermeable bedrock, e.g. seams of clay, loam and mud, the flow of surface waters slows down or completely stops. In these depressions, either lakes of open water surface formed or swampy, boggy places can be found. Their hydrological regime and soil conditions differ sharply from the wider environs and vegetation has become adapted to the local conditions. In most cases these are tiny saucers of very poor drainage; their recharge with water depends solely on the amount of atmospheric precipitation. There are riparian areas virtually without any open water surface, where a wetland habitat of local importance results from the broadened flood plain of a stream in a mountain or hill environment, with subsurface layers preventing infiltration. Characteristic wetland habitats on Pannonian sandstone in a hilly environment are found primarily in Southwest Transdanubia (Zala Hills and Outer Somogy), less frequently in the form of small natural lakes and more often in that of swamps and bogs formed on the broad flood plains of local watercourses [5].

Further wetland habitats on sandstone are known from the Balaton Upland, in the outcrops of Permian sandstone near the coast (Bálint-hegy, Küszöborra). Here, watery spots located in the depressions above impermeable layers are frequently called ‘tó’ i.e. lake (e.g. Nyálas-tó in summit position on Küszöborra range), although they completely lack an open water surface, with sedge vegetation as the only reference to the former environment. These ‘lakes’ are very small, generally less than 50 metres in diameter, and the only source of their replenishment is atmospheric precipitation. In historical times, they probably had an open water surface during humid phases, which may reappear with the recurrence of such phases. This is supported by the occurrence of lakes of similar size and characteristics in volcanic mountains of the Balaton Upland (discussed more later).

In karst regions of Hungary (Aggtelek-Rudabánya Mountains, Bükk, some parts of the Transdanubian Mountains, Mecsek and Villány Mountains) – stemming from the specific features of the regional water budget – wetland habitats are primarily confined to the relevant geological boundaries, i.e. to the contact zone between karstic and non-karstifying rocks. This is the zone of springs leaving the karst-water network (discharge) and of waters arriving from non-karstic areas and sinking into the mass of carbonate rocks (recharge). Otherwise, surface karst is not a suitable environment for the development of wetland habitats, because the mass of carbonate rocks has high water conductivity. As a result, rainwater falling on the karstic surface infiltrates rapidly into the karst-water network. (Covered karst is an exception; here wetland habitats are not confined to the contact zone and they can develop, depending on local circumstances.) Wetland habitats as a rule are associated with sinkholes (ponors). Several lakes are known that overlie former ponors which have been obturated. One of the best examples is Aggteleki-tó, with a unique flora and fauna. In spite of the fact that this highly environmentally sensitive region with a unique biota was declared a national park and strict measures of protection were introduced, this lake is exposed to pollution (mainly fertilizers) originating from the surrounding farming areas.

Wetland habitats may occur on internal karst surfaces, within the inactive dolines (usually obstructed by grains of soil or by some other way) adjusted to traces of former watercourses. One of such a typical habitat within the Aggtelek National Park is Vörös-tó at Jósvafő. In the dolines of the Bükk and Mecsek (in the latter case, very small dolines) lakes do not exist long and wetland habitats cannot survive.

Wetland habitats on karst surfaces are environmentally highly sensitive areas and immediately react to contamination of the karst-water network. Such events might lead to the degradation of the habitat, impoverishment of its biological diversity, and eventually to its complete deterioration. A further negative effect might be a change in the karst-water table, notably its sinking due to either natural trends (climate change or other slow processes affecting the catchment) or man-induced processes (water removal by pumping). The latter can cause dramatic changes and has led to severe consequences and degradation primarily in the Trans-danubian Mountains in connection with coal mining. Recently, with the decline of mining and cessation of water pumping, there has been a trend toward a rising water table and the revival of wetland habitats which had formerly dried out.

Wetland habitats might occur in local depressions in volcanic mountains due to the impermeability of outcropping effusive rocks (andesite, basalt). One of its best examples is to be found in the Mátra Mountains. The Nagy-Sás-tó natural lake (water surface area of 9 hectares, deph of 1–2 metres) is located between the settlements Mátrafüred and Mátraháza, at an altitude of 520 m a.s.l. [7]. It formed in a local depression, where both rainwater and ground waters might gather easily. Its bed is lined by a variety of andesite with an enriched content of clay minerals. The bottom layers are quasi-impermeable, preventing seepage and promoting long-standing water coverage. In this way, the emergence of the lake is the result of lithological conditions. Most of the lake floor is covered by sedge vegetation (hence its name: sás means sedge in Hungarian), but part of it has been recently removed to provide access for tourists. The rest remaining quasi-natural has botanically conspicuous reed-grass vegetation, which is protected. Some areas are closed to the public, but others can be visited and the lake is a favourite place for hiking.

One of the most interesting sphagnum bogs in Hungary is Nyirjes-tó at Sirok (found on south-eastern slopes of Darnó-hegy at an altitude of 220 m a.s.l. in an un-drained hollow of the hill Fehér-kő). The lake formed in Miocene dacite tuff, which has undergone clayification so that the lake bottom can be considered impermeable. The water is replenished only from precipitation. The lake, virtually without any open water surface and with an extension of 1,000–10,000 sq. m, accommodates a highly unique plant community with different *Sphagnum* as predominant species. Further valuable plants include willow, birch (*Betula alba*) and sedges (*Eriophorum vaginatum, Carex lasiscarpa*) [4]. In the depression around the lake, the sphagnum bog is surrounded by oak-hornbeam forest, with some beach and Turkey oak trees. It is supposed to be maintained as a shelter forest, and because of its environmental sensitivity, public access to the area is limited.

Another typical example is a wetland habitat associated with the stream Csincse-patak, which has incised in the piedmont surface of South Bükk and Bükkalja since the early Pleistocene concomitant with the subsidence of the Tisza valley. A 3.5–4 km long and 60–80 m deep erosional valley has formed. An impermeable layer can be found on its flat bottom, composed of rhyolite tuff debris and sediments transported from South Bükk. A swampy area with stagnant water has developed with rare and valuable plant species, and is being protection.

Wetland habitats occur in the Káli Basin on the Balaton Upland. They occupy the hollows on the top of the basalt plateau of Fekete-hegy (summit position). The origin of these depressions and lakes is still debatable. Some experts hold that local depressions emerged as inhomogeneities during the solidification of lava flow. Others insist that rainwater infiltrating along the joints of the basalt plateau solved out carbonates from Pannonian layers, and after a collapse of the basalt blocks, erubase soils (black 'nyirok') obturated these joints making precipitation accumulate in the hollows [3]. According to the latter concept, these tiny round-shaped lakes can be considered post-collapse doline lakes. The largest of them is *Bika-tó*, which has open surface water only during humid climatic intervals, with precipitation as the only source of recharge [1]. At present the whole area is covered by swampy-boggy vegetation.

Sphagnum bogs in Hungary are an infrequent phenomenon. They occur in places where microclimatic conditions have promoted their survival as Pleistocene relict formations. Their vegetation has preserved unique and specific species as remains of Pleistocene flora. Sphagnum lakes at Kelemér in the Aggtelek karst region are considered the most important occurrences. The lakes Kis-Mohos and Nagy-Mohos are dated at 21,000 and 15,000 years old, respectively [3,6]. In addition to the valuable flora elements preserved, sphagnum bogs contain a sequence of bottom sediments providing a reliable source of information both for Quaternary researchers and archeologists. The Mohos lakes occupy depressions which have been shaped by landslides. Sphagnum bogs are dispersed throughout Őrség, West Hungary, where abundant atmospheric precipitation, a developed and dense drainage network, and a high ground water table have promoted the evolution of bogs in general and the survival of sphagnum bogs in particular. The latter are also relatively frequent in the Zemplén Mountains. In other parts of the Transdanubian Mountains and the North Hungarian Mountains (e.g. Central Cserhát), sphagnum bogs occur much more rarely.

Wetland habitats formed in basins dammed by landslides are typical of Cserehát, a hill region on the interfluve between the Bódva and Hernád rivers. The lateral erosion of the Hernád, and the presence of Pannonian clay-like deposits as a shear surface for impermeable rocks overlain by less resistant sediments, have provoked processes of mass movement in the Pannonian sandstone and in the superimposing loess.

Artificial lakes are numerous in the mountain and hill regions of Hungary; they and the surrounding areas abound in wetland habitats. Almost all of these habitats are protected. Water reservoirs at Rakaca and

Lázbérc (North Hungary) are protected to represent biological and landscape-aesthetic values. The most widely distributed are fishponds and artificial lakes for angling and bathing (e.g. a chain of lakes at Orfű in the Mecsek). It is conspicuous that ancient Romans of Pannonia created both smaller and larger reservoirs by damming up streams running from the hills, but these later were abandoned and neglected by the population.

Former quarries have given rise to standing waters. One of its best examples is Tengerszem (mountain lake) in the Zemplén Mountains. In this place, a rhyolite tuff quarry operated as early as the 13–14th centuries, and millstone was produced from the excavated material. Quarrying continued for 400 years. During this period a huge amount of rock was excavated and a large pit emerged, where precipitation water has accumulated. Now it is 150 metre long and 50 metres wide man-made lake with a maximum depth of 50 metres flanked with steep slopes. The name derives from its position at a relatively high altitude. With its spectacularly rugged coast, the lake is a place of beauty and has high landscape value. Quarrying terminated in the early 20th century and the water was used for irrigation. Presently the lake is an object of nature conservation and the water level is mainly controlled by precipitation. Tourism and especially illegal waste disposal have led to landscape deterioration and pose a danger to the natural filling up of the lake.

3. Significance of headwater wetland habitats in Hungary

From an environmental viewpoint, headwater wetlands play an important part in reducing runoff. Due to their retention capacity, wetland habitats are capable of protecting coastal areas during storms. They slow the advancement of flood waves and facilitate the replenishment of subsurface waters. Through their runoff regulation function these wetlands balance (or at least move toward equilibrium) the hydrological regime of the primary catchments, thus reducing differences between high and low water levels. Naturally, the scale of these effects depends on the character, size, capacity, and geographical setting of the wetland habitat in concern. This buffering character of wetland habitats in Hungary is not pronounced, because of their dispersed distribution and very limited extension. Larger water reservoirs in the internal areas of mountains are the only exception.

Wetland habitats receive moisture after slow penetration through a media rich in vegetation and micro-organisms. This process is instrumental in the maintenance and improvement of water quality.

Wetland habitats as systems are capable of absorbing nutrient surpluses such as nitrogen and phosphorus, which derive from the use of fertilizers in agriculture, and behave as sediment traps; they also promote neutralization of certain chemical and organic wastes. Habitats on primary catchments are particularly sensitive to pollution and may affect the lower stretches of streams.

The landscape-aesthetic and recreational function is highly important in Hungary; wetland habitats are attractive and can generate considerable income. Profit-making functions include tourism and leisure time activities (e.g. angling, bathing). However, environmental pollution and landscape degradation caused by tourism should be a primary concern; these harmful effects must be kept within reasonable limits. Where it is necessary for the protection of the habitats of endangered species, the number of visitors must be restricted and/or part of the area should be closed for public attendance.

Wetland habitats play an important part in education and research. These field laboratories should be involved in several environmental education and research programs. Similar activities may focus on a specific plant or animal species, or some wetland habitat functions. Alternatively, they can be put into a broader context, e.g. seeking to establish relationship between the behaviour of wetland habitats and global climate change. Wetland habitats might also be a venue for experiments with newly appearing (immigrant or invasive) species or for testing adaptation of indigenous species to new environmental conditions [2].

Wetland habitats sustain a large number of plant and animal species, including numerous rare and endangered ones. These spots are feeding and nesting places and stop points in migration for water fowls and other kind of birds. From the nature conservation point of view, they provide niches for endemic species. The valuable yellow and black spotted land salamander (*Salamandra maculosa*) is an illustrative example, as it only occurs in headwater wetland habitats of the country. In this respect sphagnum bogs are highly important: the one at Ócsa preserves some unique species of orchids (e.g. *Ophryes sphecodes*) whereas another at Bátorliget is a refuge of Pleistocene flora and fauna species. (These latter, however, are wetland habitats in the Great Hungarian Plain.)

Headwater wetland habitats present an important landscape-ecological barrier for certain species, whereas they function as corridors for others. The character of such habitats is decisive for the composition of the plant community living there. As an example, two relative amphibian frogs living in Hungary, bellied toads, are immigrant species. They are natives of the Caucasus and migrated along the southern coast of the Black Sea (Pontic Mountains), crossed the Bosporus and the Balkans, passing through a chain of wetland habitats forming ecological corridors, until they reached the Carpathian Basin. Their ecological requirements, however, are different: *Bombina bombina* is a flatland species, whereas *Bombina variegata* lives in headwater wetland habitats.

A further importance of wetland habitats is their indicator function. This is especially valid for the smaller, highly sensitive places where natural wetland ecosystems have survived. Stemming from the basin character of Hungary and its central geographical setting in Europe, the country is located in a collision zone between huge centres of action that determine weather conditions. Plant communities to be found here which are adapted to climate change store more abundant information regarding past climate changes, whether within a limited area or in the whole Carpathian Basin, than meteorological data sets elaborated by mathematical-statistical analysis.

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HEADWATER WETLANDS IN THE CZECH REPUBLIC

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KEYWORDS / ABSTRACT: Headwater wetlands / Ramsar sites / forest decline and recovery / Acid atmospheric deposition / forested wetlands / herbaceous vegetation / run-off genesis / surface water chemistry / recovery

In the Czech Republic, the Ramsar Sites include two headwater wetlands (6,601 ha). Considering the task of headwater control, a database of mountain peat-lands does not exist. However, 1,900 peat-land sites have been identified by inventories done in the 1950-1960s. Unfortunately, no exact information on the historical loss or conversion of wetlands is available. The current Czech legislation on the protection of the environment is based on the concept of a ministerial approach, which is not well suited to ensuring sustainable development. Generally, the existing legislative is effective in the conservation of limited spots. Unfortunately, an integrating approach reflecting global aspects of environmental problems is still missing.

1. Introduction

Headwater wetlands provide watersheds with large range of downstream benefits. Traditionally, it is widely considered that they serve important ecological functions in supporting biodiversity and preventing downstream flooding by absorbing precipitation, [9]. Recently, mountain bogs have been recognized for their role in regulating the global climate by storing large amounts of carbon in peat deposits [7, 9]. However, headwater wetlands are fragile components of a watershed. They need special control - including conservation, protection and integration in the process of watershed planning, [2, 3].

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 265–270.

2. Inventory of wetlands in the Czech Republic

Wetlands International [1] proposes that there are 1,989 wetland sites (116,987 ha) in the Czech Republic:

- 10 Ramsar sites of an international importance (41,876 ha),
- 56 wetlands of national importance (18,667 ha),
- 442 wetlands of regional importance (32,552 ha),
- 1,481 wetlands of local importance (23,892 ha).

Unfortunately for headwater control, a database of mountain peat-lands does not exist. However, 1,900 peat-land sites have been identified by inventories done in the 1850s, and in the 1950-1960s [1], [5]. No exact information on the historical loss or conversion of wetlands is available.

3. Wetlands of international importance

The Czech Republic has 10 Ramsar Sites (41,876 ha), wetlands that support biodiversity of international significance and these include 2 headwater wetlands (6,601 ha):

3.1. PEATLANDS OF THE SUMAVA MOUNTAINS

In 1990, the "Peat-lands of the Sumava Mountains" (Ramsar Site No. 494, area of 6,371 ha, elevation 730 to 1,200 m a.s.l.) was proclaimed in the Sumava Mts. National Park. This unit represents a non-forested wetland with shrubs, open bogs and swamps. Its main role is entomological conservation (especially of 25 species of butterflies).

3.2 MIRES OF THE GIANT MOUNTAINS

In 1993, the "Mires of the Giant Mountains" (Ramsar Site No. 637, two units, area of 230 ha, elevation 1,300 to 1,440 m a.s.l.) was proclaimed in the Giant Mts. National Park. The two units represent forested wetlands as well as Alpine meadows and open bogs. The main task is to support bird communities, relicts and endemic species in general.

4. Policy

Two above-mentioned headwater wetlands of international importance (Ramsar Sites 494 and 637, area of 6,601 ha) are conserved according to the Ramsar convention [1]. However, a large number of mountain wetlands have been protected in the frame of the existing policy on the conservation of water and forest resources [2].

In the Czech Republic, headwater areas have been controlled mainly by the Act on Nature Protection (1967, Czechoslovak Ministry of Culture) and by the Decrees on Protected Headwater Areas (9/1978 and 2/1979, Czech Government). The act on Nature Protection regulates the regime of protection on a regional scale (National Parks and Protected Landscape regions) as well as the conservation of small units (State Nature Preserves; particularly some unique natural forest stands and mountain peat-bogs). The main task of the Decrees on Protected Headwater Areas is to control hydrological phenomena (particularly the water outflow from a catchment: quantity and quality); the area concerned is 864,500 ha.

Since 1975, several headwater peat-lands in watersheds, which are important for the drinking water supply, have been also protected by the Decree on Hygienic Buffer Zones (28/1975, Ministry of Public Health). The main idea of this decree is conservation again: to exclude local human activities and potential contamination of the water.

The headwater areas of the Czech Republic are mainly forested (16% of the total forest area is located in headwaters). Peat-land sites are significant elements of forested wetlands. playing an important role in water and soil conservation as well as in the protection of downhill areas against floods. Therefore, environmentally sound forestry practices are important in headwater control (particularly, deforestation, clear-cut, drainage of peat soils, and peat harvesting).

Since the 1990s, there is an effort in the national legislature to meet EU standards (Law 244/1992 on Environmental Impact Assessment, Law 123/1998 on the Information on the Environment). However, the current Czech legislation on protection of the environment is still based on the concept of a ministerial approach, which is not well suited to ensuring sustainable development. Generally, the existing legislature is effective in the conservation of limited spots. However, an integrating approach reflecting global aspects of environmental problems is still missing.

5. Changes in mountain forested wetlands

In the past, the dominant native tree species of mountain forests in the Czech Republic were Common Beech (*Fagus sylvatica*), Norway Spruce (*Picea abies*) and Common Silver Fir (*Abies alba*). The significant changes in mountain forests occurred namely in the 19th century. Nowadays, 90% of mountain forests in the Czech Republic are spruce plantations. Such a situation has led to a lower stability of mountain ecosystems, and, by the end of the 19th century, several large-scale insect epidemics occurred. An urgent need to return forests to a near native composition is evident. Besides species conversion, the decline of mountain forests has been caused by the acid atmospheric deposition, global climate change, commercial forestry practices (large-scale clear-cut, use of heavy mechanization, drainage of peat-lands) and insect epidemics [5], [6], [8].

During the last century, the Earth's average surface temperature rose by around 0.6°C, [4]. Evidence is getting stronger that most of the global warming that has occurred over the last 50 years is attributable to human activities. IPCC [4] predicts that global average surface temperatures will rise by a further 1.4 to 5.8 °C by the end of this century. The expected climate change might include also 3 to 15 % rise in the mean annual precipitation [5].

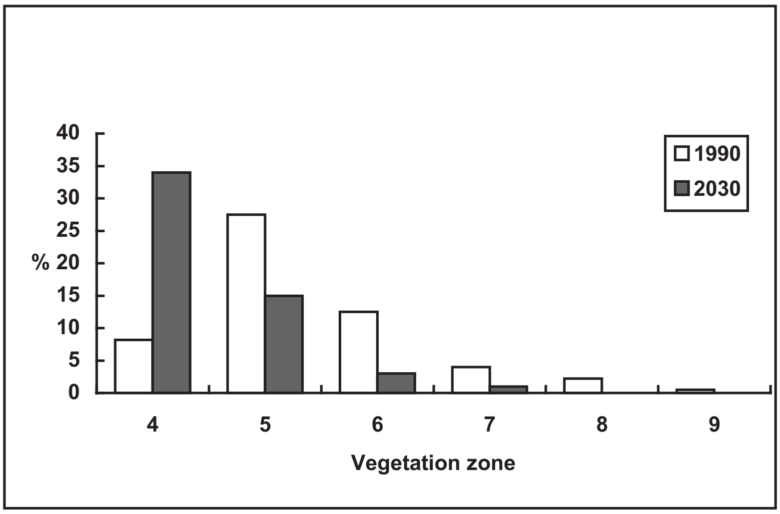

Figure 1. The potential changes in mountain climax vegetation zones (Czech Republic), [5].

In the Czech Republic, mountain forests include 6 climax vegetation zones (4 - 9): 4 (beech, mean annual temperature: T_a = 6.0-6.5°C and mean annual precipitation: P_a = 700-800 mm), 5 (fir-beech, T_a = 5.5-6.0 °C, P_a = 800-900 mm), 6 (spruce-beech, T_a = 4.5-5.5 °C, P_a = 900-1050 mm), 7 (beech-spruce, T_a = 4.0-4.5 °C, P_a = 1050-1200 mm, 8 (spruce, T_a = 2.5-4.0 °C, P_a = 1200-1500 mm), and 9 (dwarf pine, $T_a < 2.5$ °C, $P_a > 1500$ mm).

Possible future changes in mountain climax vegetation zones following results of the climatic models are in Figure 1.

However, predicted climate changes have a high degree of uncertainty. The predicted change in water yield from a mountain forested catchment ranges from - 32% to +10% [5].

Since the 1960s, the percentage of salvage cutting in the Czech Republic has increased due the air pollution damages and dieback. Nowadays, 75% of mountain forests are significantly damaged by the consequences of the air pollution, and 25% of them are devastated, [5], [6]. Since 1990, a significant drop in the atmospheric deposition of sulphate in mountain regions of the Czech Republic has been observed (cca 40% in comparison with the year 1987). Krecek and Horicka [6] report the recent recovery of surface waters in mountain watersheds (including the reintroduction of fish) observed since the beginning of the 1990s. This recovery results, particularly. from the reduced air pollution, significantly suppressed leaf area and roughness of the canopy by the harvest of mature spruce forests), environmentally sound forestry practices (skidding of timber by horses or cable-ways, control of peatlands, melioration of erosion rills, support of stands near to the native composition), and liming of both reservoirs and watersheds.

6. Conclusions

Headwater forested wetlands are facing several aspects of changing mountain forests (global warming, acid atmospheric deposition, commercial forestry). The current Czech legislation on protection of the environment is still based on the concept of a ministerial approach, which is not well suited to ensuring sustainable development. Generally, the existing legislative is effective in the conservation of limited spots. Unfortunately, the integrating approach reflecting global aspects of environmental problems is still missing.

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ANALYSIS OF THE WATER BALANCE OF SMALL PÁRAMO CATCHMENTS IN SOUTH ECUADOR

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KEYWORDS / ABSTRACT: páramo / water balance / hydrological monitoring / evapotranspiration / seasonality / human impacts.

The páramo is a high altitudinal wetland ecosystem in the upper Andes of Venezuela, Colombia, Ecuador and northern Peru. It is a reliable and constant source of high quality water and as such, the major water provider for the Andean highlands and part of the coastal plains. Water is used for consumption as well as electricity production. However, scientific evidence suggests that the quality and quantity of this water source may be at risk, due to increasing human interference in the wetland ecosystem. The current study analyses the water balance of two microcatchments near Cuenca, Ecuador. One is covered by the typical natural grass vegetation, while the other catchment is heavily interfered and intensive cultivation, cattle grazing and drainage are taking place. Three rain gauges and a V-notch were installed in each catchment, and one meteorological station in a nearby location. Analysis of the precipitation data reveals that seasonal variability in the páramo is extremely low. This property is a major reason for the sustained base flow, which characterises the páramo. However, evapotranspiration, represented by the crop coefficient, is more than twice as high in the cultivated areas (0.95), compared to the natural vegetation (0.42). The increased evapotranspiration may seriously affect the water production of interfered páramo catchments. Finally, based on water balance analysis, the variation in water storage in the páramo is very low, with a yearly variation of about 25 mm. In the interfered catchment, the storage in variation is even lower, about 15 mm, suggesting a deterioration of the regulation capacity.

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 271–281.

1. Introduction

The páramo is a neotropical ecosystem located in the upper Andean mountain region, between the tree border and the eternal snow line (Medina and Vasconez, 2001). Depending on the local geographical and climatic conditions, these limits correspond roughly to an altitude of respectively 3500 and 5000 m altitude. The ecosystem is characterised by a tundra-like vegetation consisting of tussock-forming grasses, small herbs and xerophytic shrubs, with scarce patches of *Polylepis sp.* bushes [9, 8, 14]. The climate is cold and wet. Precipitation ranges between 1000 and 3000 mm year^{-1} and the average daily temperature is about 8°C at 3500 m altitude [5].

The páramo is known for its large water supply and good water regulation. Precipitation is moderate, but the real water input in the hydrological system is probably significantly higher. Rainfall events in the páramo are typically of high frequency and low intensity. In combination with strong winds and a very irregular topography (rain shading) this may result in a high spatial rainfall variability and large errors in precipitation registration. Additionally, "horizontal rain", i.e. precipitation due to fog and dew, may add an unknown quantity of water to the hydrological system, especially where patches of arbustive species such as Polylepis are present. This mechanism is similar to occult precipitation in the lower montane cloud forest, where it typically adds 5 to 20% of ordinary rainfall [4, 2]. On the other hand, natural water consumption in the páramo is very low, because of the predominance of tussock grasses and xerophytic herbs with low evaporation characteristics, despite the high evaporative force of UV-radiation at this altitude and latitude. As a result, there is a large water surplus, feeding the rivers descending to both the coastal regions and the Amazon basin.

Due to the cold and wet climate and the lack of seasonal variation in precipitation, the páramo is a constant and reliable source of high quality water for the Andean regions of Ecuador, Colombia and Venezuela. Water is used for urban, industrial and agricultural purposes. Besides direct water consumption, the water supply function is of economic importance as it feeds many hydropower plants, located both in the páramo itself as well as in the dryer, lower Andean regions. In Ecuador, hydropower accounts for more than 50% of the total electricity production [12]. All together, it is estimated that the high Andean wetlands, of which the páramo forms a major part, provide environmental services to more than 100 million people [10]

For ages, the páramo has remained a natural ecosystem with only minor human activity. However, recently, human interference has increased drastically, because of population growth and expansion of urban areas, as well as soil degradation in the lower regions. Grassland is converted for the cultivation of potatoes and beans, and natural vegetation is replaced by more nutritive grass species. These changes are suspected to alter significantly the hydrological cycle of the páramo, thus endangering its water supply function. The current study aims at a detailed analysis and uncertainty estimation of the water balance of two microcatchments in the páramo of the rio Paute basin (south Ecuador) in order to determine the impact of agriculture on the water production of the páramo ecosystem.

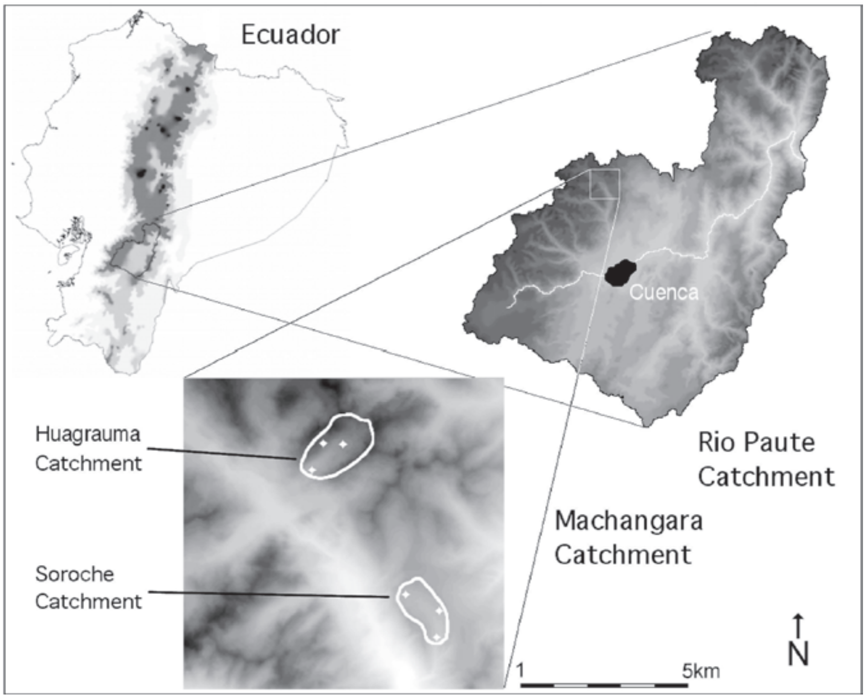


Figure 1: Location of the experimental catchments Huagrauma and Soroche.

2. Materials and Methods

2.1. Location

The experimental catchments *Huagrauma* (2.58 km^2) and *Soroche* (1.59

km^2) form a part of the Rio Machangara basin, located in the NW Rio Paute basin (Fig.1). The Huagrauma catchment is covered by the typical, natural tussock grass vegetation, with scarce, scattered patches of Polylepis trees. The altitude ranges between 3690 and 4100 m. Except for some extensive grazing, human influence is minimal. The borders of the catchment consist of steep slopes, up to 60% and more. At the foot of these slopes, flat areas exist, where bog vegetation develops and regular ponding occurs. Due to the highly dynamic and seasonal nature of the ponds and marshes, it is difficult to estimate their total area in the catchment.

The Soroche catchment is 38% smaller than the Huagrauma basin and ranges between 3520 and 3720 m altitude. This catchment is heavily disturbed by human influence. 30% of the catchment area is used for intensive grazing and cultivation (0.48 km^2). In this area, the original vegetation is cleared and eventually replaced by more nutritive grass species. The soil is drained intensively with an irregular network of open trenches, about 0.7 m deep (up to the subsoil level), with an average distance of about 20 m or less. During the study, the drainage has expanded in additional parts of the catchment, covering an additional estimated 20% of the catchment surface. Compared to the Huagrauma catchment, the slopes of Soroche are gentler and the topography is less accidented. Ephemeral saturation and ponding occurs regularly at the foot of hill slopes.

2.2. Monitoring

Each catchment is equipped with three tipping bucket rain gauges, with a resolution of 0.2 mm. The location of the rain gauges is indicated on Fig. 1. At the outlets, the catchment runoff was measured every 15 min using a V-notch construction and a water level logger. The Kindsvater-Shen relation [13] is used to convert the water level to discharge.

Radiation, temperature, humidity and wind speed were recorded at a 30 min. interval at a meteorological station near the Chanlud dam site. This station is located at a distance of resp. about 2400 and 4600 m from the center of the Huagrauma and Soroche catchment. From these data, the daily reference crop evapotranspiration (ET_o) in the catchment was calculated using the FAO Penman Monteith method [1]. The temperature data were corrected for the difference in altitude. Herefore, a calibration curve was constructed with local mean annual temperatures at different altitudes [3]. Some gaps in the daily minimum temperature, daily maximum temperature and minimum relative humidity were closed using the correlation with the average daily radiation. The Pearson correlation coefficients (r) are respectively -0.56, 0.87 and 0.89. Lacking maximum relative humidity values were set at 100%, as 93.4% of the registered daily maximum relative humidity values reach 100%.

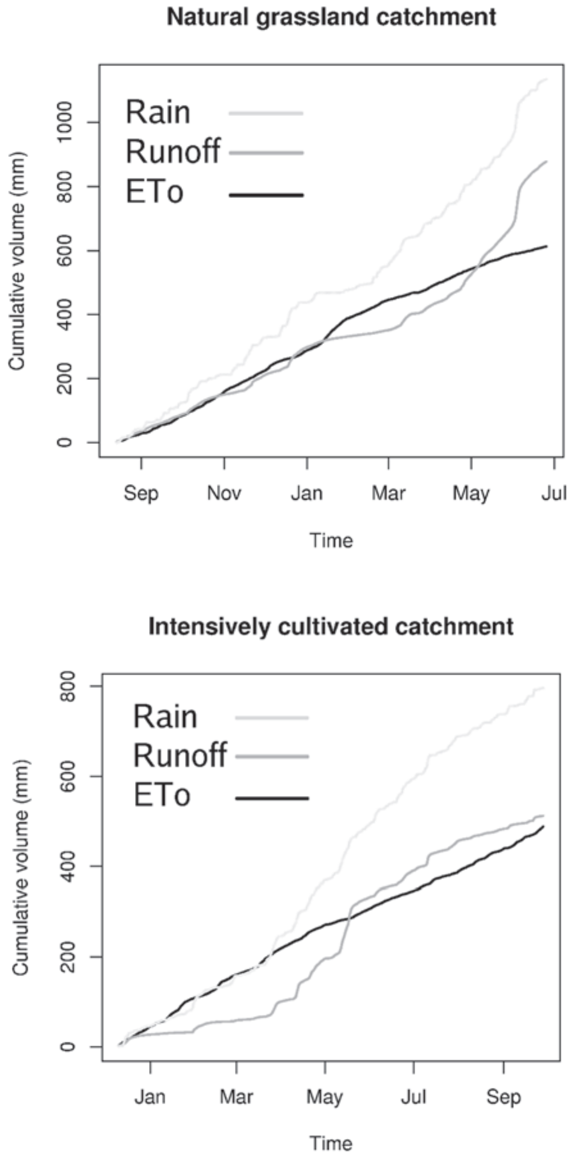
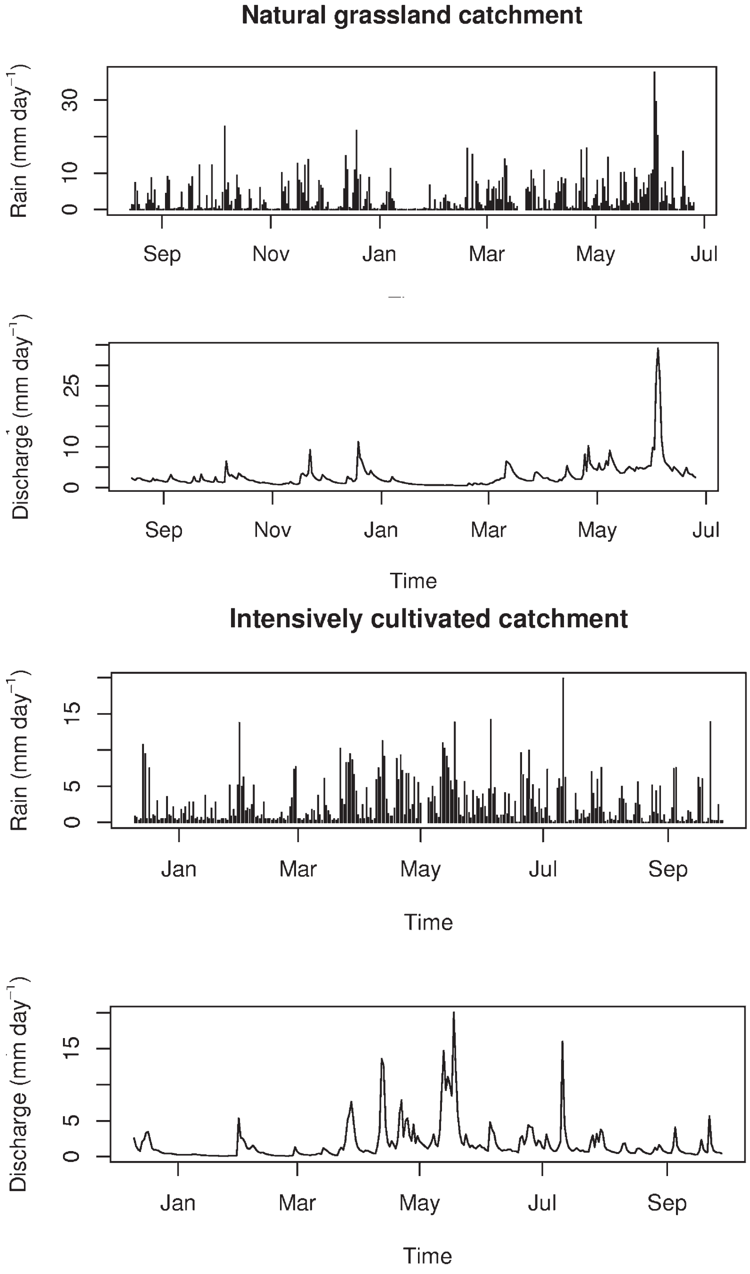


Figure 2: Cumulative rainfall, runoff and reference crop evapotranspiration over the monitored periods for the studied catchments.



Natural grassland catchment

Intensively cultivated catchment

Figure 3: Rainfall- runoff in the natural Huagrauma and the cultivated Soroche catchment

The periods in which the two catchments are compared do not match due to failures in the discharge measurements. For Huagrauma, data from 09/2003 to 07/2004 were used, and for Soroche from 01/2003 to 09/2003. This is not seen as a major problem, due to the lack of seasonality in the páramo and the large homogeneity in rainfall and weather (Fig. 2). Further advantages of this lack of seasonality are:

- The crop coefficient K_c for both the natural vegetation and cultivated crops does not change during the year. The natural vegetation is perennial without seasonal growth stages.
- The water storage in the catchment, both in the soil and in the vegetation, is rather constant. This allows for water balance calculations over short time periods.

3. Results and Discussion

Precipitation and discharge over the monitored periods are given in Fig. 2 for both catchments. In the lower Andean highlands, a bimodal climate exists, with two dry periods, from July to August and from Januari to March. This seasonal fluctuation is visible in the rainfall pattern in the páramo, but it is very low, compared to the other regions. In general, the linearity of the graphs approves the lack of clear seasonality in the páramo.

Fig. 3 shows the cumulative precipitation, discharge and reference crop evapotranspiration in the Huagrauma and Soroche catchments. From these data, the water balance of the catchments can be calculated. The water balance of the catchment can be written as:

$$\text{Rain} + \text{Interception} = \text{Evapotranspiration} + \text{Runoff} + \text{Infiltration}$$

In the Penman Monteith calculation method, evapotranspiration is expressed as follows:

$$ET = K_s * K_c * ET_o$$

with ET_o the reference crop evapotranspiration, K_c a crop coefficient and K_s a water stress factor.

The shallow soils and compacted bedrock, as a result of glacial compaction during the Tertiary (Buytaert et al., 2005), allow no deep infiltration, thus this term can be neglected. It is also unlikely that horizontal precipitation and interception of fog and mist, often found in cloud forests, add a significant quantity of water to the hydrological cycle. Fog and mist are very common in the region, but the interception is generally attributed to arbustive vegetation, which is lacking in both catchments. Finally, K_s can be set at 1, because water stress is non-existing. Former studies (Buytaert, 2004) showed that in the páramo, the soil water content seldomly decreases beneath field capacity.

When these simplifications are taken into account, the only unknown factor in the water balance is the crop coefficient. The water balance was solved for the monitored periods, in which it was assumed that the difference in water storage in the catchment can be neglected. In view of the lack of seasonality in the páramo, a one year monitoring period is likely sufficiently long to make such an assumption. The resulting K_c for Huagrauma is 0.42, while for Soroche it is 0.58. For the natural Huagrauma catchment, where the natural vegetation is homogeneous, the calculated value is likely to correspond to the crop coefficient of the natural graminaceous vegetation. A value of 0.42 is realistic.

Contrary to most grass species, the páramo grass tussocks consist of up to 90% of dead leaves, thus greatly reducing evapotranspiration (Hedberg, 1992). For the interfered cathcment Soroche, the physical representativity of the calculated crop coefficient is less clear. It integrates evapotranspiration from the natural vegetation, the increased transpiration of exotic grasses and crops, as well as evaporation from fallow fields, drainage canals and degraded areas. The interfered area in the Soroche catchment is about 30% of the total area. The remaining 70% is covered with the same natural grass vegetation as Huagrauma, and thus probably has a similar K_c of about 0.42. If this is taken into account, the interfered area in Soroche has an overall K_c of about 0.95, which is twice the K_c of natural grassland. A higher evapotranspiration is directly correlated with a lower water yield, which may greatly affect the many water collecting activities in the páramo and trigger a competition in water use between the lower urban areas and the local agricultural practices.

Fig. 4 shows the daily variation in water storage in the monitored catchments, using the calculated crop coefficients to close the water balance. As was hypothesised before, the maximum variation in water storage in the natural catchment is very low: less than 25 mm. Nevertheless, the variation in water storage of the interfered catchment is still significantly lower (< 15 mm). This may be an indication of a decrease in water storage and regulation capacity in this catchment. Such a conclusion would be in accordance with other literature (Buytaert et al., 2004). However, at present, the exact mechanism of the loss of water regulation as a result of intensive cultivation is still unknown, and further investigation is therefore recommended.

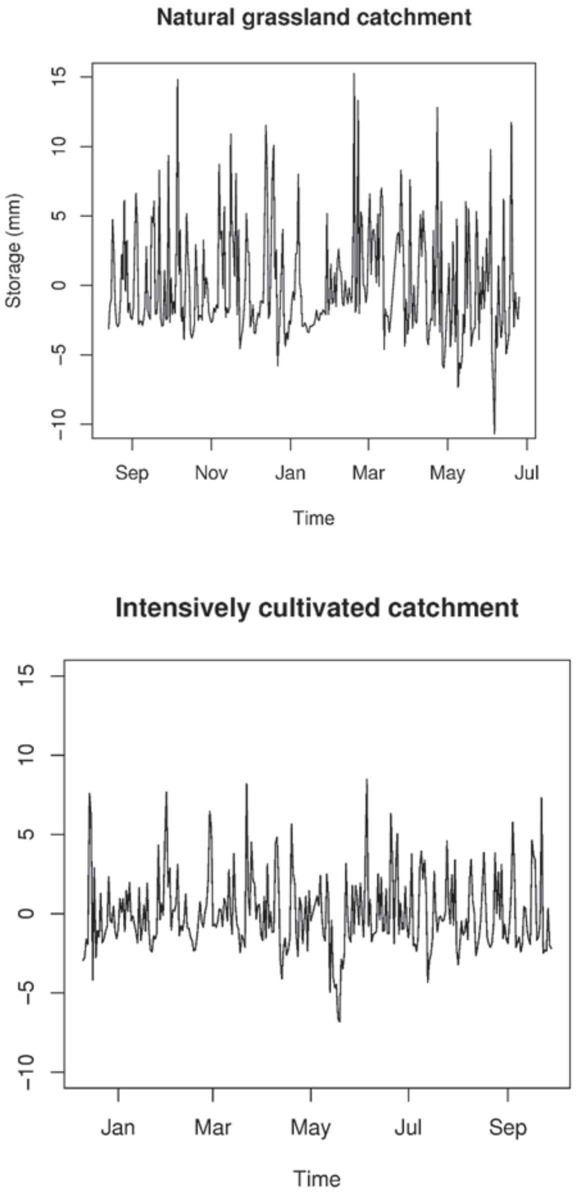


Figure 4: Variation in water storage in the monitored catchments.

4. Conclusions

After studying the water balance of 2 microcatchments in the Ecuadorian páramo ecosystems, the following conclusions can be drawn:

- Precipitation over the year is homogenous and lacks strong seasonal variability.
- The crop coeffient of the natural vegetation is estimated 0.42, which is a realistic value in view of the vegetation characteristics.
- For the cultivated catchment, the overall crop coefficient for the cultivated area is estimated at 0.92. The large difference with the natural vegetation may cause problems in water supply systems using water from these areas.
- The variation in water storage capacity in the catchments is low, with a maximum variation not exceeding 25 mm. The variation in the cultivated catchment is even lower (15 mm), which may indicate a loss in water storage and regulation capacity.

5. Acknowledgements

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SUMMARY REPORTS:

Wetlands in Slovakia, Poland, Belarus, Slovenia and Canada

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KEYWORDS / ABSTRACT: wetlands / summaries / Slovakia – Ramsar Sites / / Poland – mountains, biodiversity / Belarus – bogs / Slovenia – water balance Canada – permafrost.

This is a collection of short reports on headwater wetlands in Slovakia, Slovenia, Poland, Belarus and Canada. In Slovakia, the convention on Wetlands came into force for the Slovak Republic on 1st January 1993. The Slovak Republic has 1900 registered areas, with 1379 important wetlands. In the group of 12 wetlands of international importance, 2 are headwater wetlands. The key law for nature conservation is the Act on Nature and Landscape Conservation (law 287/1994). Its advantage is the complex protection of nature and landscape. In Poland, peat-lands are very important components of the environment and landscape, because they retain great amounts of water as well as organic matter. The accumulation of organic matter in peat-lands of Poland has been estimated at about 3 million tons. On this terrain, over 200 species of bryophytes and about 650 species of vascular plants have been found. High biodiversity typical for Poland's peat-land flora and the vegetation differs from other peat-lands of Europe. The quantity of massifs and individual small raised bogs in Belarus numbers about 1650. The disposition of raised bogs on the territory of Belarus is affected by physical and geographical and botanical

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gradients. Their area decreases towards the south direction and great-salient bogs with ridge-pool-complexes are replaced by weakly domed bog massifs with ridge-pool-palsa complexes. For the purpose of preservation of the unique plant complexes of raised bogs, a network of specially reserved natural territories has been created, which covers 248 thousand ha (78 %) of oligotrophic massifs of Belarus. The raised bogs of Belarus are reserved on the territory of 2 preserves, 90 reserves, and 4 National Parks. In addition, 7 reserves of bitumen-hydrolytic raw materials have been created. Slovenia (20.000 square kilometres) has one of the highest levels of precipitation in Europe: the majority of the country receives more than 1500 mm per year and the highest amounts are above 3500 mm per year. This abundant precipitation is caused by moist south-westerly winds along the slopes of the Julian Alps. In these areas, very large hourly and daily precipitation is observed. Daily precipitation exceeds 400 mm. Canada has Wetlands cover 14% (1.48 10^6 km^2) of the country and this amounts to 25% of the world's wetlands. Permafrost melting could result 60% increased capacity and retention times. This could result in reduced peak flows following snowmelt and high rainfall events. It could also increase year-round base flows in affected drainage basins.

1. Headwater Wetlands in Slovakia (S. Markova)

1.1. INTRODUCTION

In the past many wetlands in Slovakia (more than 4500 km^2 of land) were drained for agricultural land and transformed into fields. After drainage, the underground water table decreased drastically, and additional irrigation became necessary. Wetlands have been rapidly disappearing and with them a great number of unique living organisms have gone extinct. In the last ten years, global attention has increased with the aim to save threatened, conserve and restore wetlands. They are considered to be the most threatened ecosystems of the world. Wetlands include marshes, swamps, bogs, flooded forests and meadows, which are able to be found from the submontane to the lower part of the alpine zones in the Tatras, Liptov, Orava, Turiec, Spiš and Pohronie regions.

1.2. THE RAMSAR WETLANDS

The convention on Wetlands came into force for the Slovak Republic on 1st January 1993. The Slovak Republic has 1900 registered areas, with 1379 important wetlands categorized as:

- 12 wetlands of international importance
- 69 wetlands of national importance
- 4 wetlands of super-regional importance
- 383 wetlands of regional importance

- 911 wetlands of local importance

1.3. Wetlands Of International Importance (38,208 Hectares)

- Domica Cave: Protected Landscape Area, World Heritage site, 622 ha
- Danube flood plains: main channel of Danube River and its floodplain, 14,488 ha
- Latorica: Protected Landscape Area, Nature Reserve, 4,405 ha.
- Morava flood plains: Protected Landscape Area, 5,380 ha
- Paris marshes: Protected Site, 184 ha
- Senné fishponds: Nature Reserve, 425 ha
- Súr: Nature Reserve, 1,137 ha
- Turiec wetlands: National Nature Reserve and Protected site, 467 ha
- Wetlands of Orava Basin: Protected Landscape Area, Important bird sanctuary, 9,264 ha

1.4. Headwater Wetlands

*1.4.1. Orava river and its tributaries: 865 ha, 48°14'N 019°28'E.*_The river system is natural except for the Orava reservoir. The whole river system is relatively natural, ecologically stable and has good water quality. It plays an important role in the accumulation of surface water and groundwater, and in maintaining the water regime of the Orava river catchment. The whole river ecosystem offers temporary or permanent habitats for 50 species of vulnerable, rare or endangered vertebrates; mammals, birds, reptiles, amphibians, and fish, as well as several invertebrate species. The stream system contains more than 35% of the entire fish fauna in Slovakia.

*1.4.2. Poiplie: 411 ha, 48°04'N 019°01'E.*The Ipel' River and its alluvial floodplain are important for groundwater recharge and for maintaining the hydrology of the area. Due to the width of the floodplain and the meandering nature of the river, there is little risk of flooding in the downstream area. The site is linked with extensive wetland ecosystems in Hungary and plays a key role in the natural functioning of the Ipel' River catchment. The main area is the Ipel' River, a unique complex of well-preserved wetland habitats. Marshes, seasonally flooded grasslands, floodplain forest and scattered patches of willow scrub are important habitats for migratory birds, mammals, amphibians, spiders and dragonflies.

1.4.3. Rudava River Valley: 560 ha, 48°31'N 017°09'E. The Rudava River is a small tributary of the Morava River and has a total length of approximately 45 km. The river flows through a complex of inland sand dunes established during interglacial periods, thus providing two starkly contrasting landscapes with very different hydrological regimes and ecosystems. It has a well developed complex of wetlands including the river and its tributaries, oxbow lakes, sandbanks, peat bogs, fens, reedbeds, flooded forest, swamp, and wet meadows. There were found 505 plant species, 101 of which are on the Slovakian Red List of flora, 30 fish species with 5 on the Red List, 13 species of amphibians and 5 species of reptiles with 4 on the Red List, 48 species of birds with 13 on the Red List and 24 mammals. In 1996, this list included 780 locations which cover 53 million hectares. The Slovak Republic has nominated the following locations: Šúr, Parížske močiare, Čičovské mŕtve rameno and Senné rybníky. The wetlands areas of the Orava, Turiec and Ipeľ rivers are now being prepared for nomination.

1.5. POLICY

In 1948, the concept of nature conservation originated in the Tatra National Park, and in 1955 the first Nature Conservation Law Act was proclaimed. Further important developments were the concept of the protected landscape areas in Slovakia (1964), preventive nature conservation measures (1970-1975), further supported especially by the Project of the development of protected areas till the year 2000 (1981) and Concept of the development of State nature Conservation till 2005. A shift to higher quality was realized with the elaboration of the concept of the Territorial Systems of Ecological Stability (TSES) and by the adoption of the new Nature and Landscape Conservation Act (1994), valid from January 1, 1995.

1.6. WETLAND MANAGEMENT

Wetland management is created by the combination of a large number of new laws dealing with the conservation of nature, landscape, and individual components of the environment adopted after 1989 (the Environmental Law, the Agricultural Soil Fund Protection Law, the Air Protection Law, the Minerals Use and Protection Law, the Environmental Impact Assessment Law, Nature and Landscape Conservation Act). Many older laws have been renewed after 1989, (e.g. about forestry, water management, hunting, building, regional planning). Also significant is the

Green Article of the Constitution of the Slovak Republic, according to which, each citizen has the right to a healthy environment as well as a duty to protect the environment, nature and cultural heritage.

The key law for nature conservation is the new Nature and Landscape Conservation Act (law 287/1994). Its advantage is the complex protection of nature and landscape. The whole territory of Slovakia is divided into 5 zones of differing conservation levels. The categories of the protected areas are defined according to IUCN criteria. The law includes compensation for property damages due to nature conservation precautions.

The Nature and Landscape Conservation Act No. 287/1994 defines the following categories of landscape protection:

- I (lowest) degree - general protection applied for the whole territory of Slovakia,
- II degree - Protected Landscape Area, Protective Buffer Zone of National Park,
- III degree - National Park, Protective Buffer Zone of Protected Area,
- IV degree - Protected Area, Protective Buffer Zone of Nature Reserve, Protective Buffer zone of Natural Monument,
- V degree - Nature Reserve, National Nature Reserve, Natural Monument, National Natural Monument

1.7. CONCLUSION

The moral imperative is 'what you can not create, do not destroy'. With the declaration of the Ramsar Convention, people have gained a better understanding of wetlands, their importance for nature and sustainable human living. The results of this convention have been a key tool in the conservation of strategic water sources.

2. Mountain Peat-Lands in Poland (K. Haponiuk-Winiczenko)

2.1. INTRODUCTION

In mountain regions of Poland, peat-lands are only an inconspicuous part of the ecosystem. All peat-land areas are legally protected by the Environmental Protection Act, the Nature Conservation Act and the Water Act. They are inventoried in detail. Peat-lands in mountain regions of

Poland are in the Polish Izerskie Mountains, the Karkonosze Mountains, the Podhale and Tatra Mountains, and also in the West Bieszczady.

2.2. INVENTORY OF MOUNTAIN PEAT-LANDS IN POLAND

In Poland, all 51,069 peat-lands have an area of about 1,307,000 hectares, which is 4,2% of the country territory [3]. Nearly 90% of this area is accounted for by fens, while raised bogs account for about 6% and the other 4% is accounted for by transitional bogs. A large majority of peat-lands are located in the northern part of Poland –about 75% of the wetlands occur there. The central part of Poland has 24,3% of the total area while the entire southern part has only 1,5% [2]. The territories located higher than 300-350 m above sea level are classified as mountainous areas. They are divided into foothills (300-500 m) and mountains (over 500 m). Those areas contribute about 9% of the total land of Poland. Mountains regions are located in the Carpathians, Sudeten and the Gory Swietokrzyskie mountains.

In the Polish Izerskie Mountains, there are a few peat-lands with a total surface of about 500 hectares, which is the largest complex of peat-lands in mountains in all of Central Europe. They are 800-1000 m above sea level. These peat-lands are called 'mszary izerskie'. They have many common characteristics with peat-lands in the Karkonosze Mountains. The dominant plant communities are *Carex fusca, Sphagnum* and *Eriophorum*. There is also a very interesting area where you can find a special type of *Betula* growing only up to 1 m high. These species are typical for polar tundra. The most characteristic peat-land of the area of the Izerskie Mountains is the peat-land on 'Hala Izerska'. It is 14 ha in area and contains two species of insectivorous plants - *Drosera rotundifolia* and a very rare species - *Drosera longifolia* [3].

In the Karkonosze Mountains the surface area of peat-land is about 85 ha. About 20 ha of this amount are peat-lands of the sub-alpine zone at the elevation of 1250-1440 m, while the other 65 ha are located between 1100-1300 m. They are gravity fed, so they are very poor in nutrients. Due to the large site elevation drop, big parts of these peat-lands are subject to drought that leads to a periodic decay of growing processes. The diversification of conditions at the *Pinus mugus* zone has allowed the formation of various plant communities, such as a community with *Empetrum nigrum, Vaccinium uliginosum*, *Calluna vulgaris*, *Eriophorum* or *Eriophorum vaginatum* [3]. On some of the peat-lands there are very rare species which are glacial relics, such as *Rubus chamaemorus* or *Sphagnum Lindbergii* .

In the Tatra Mountains, there are a lot of very small peat-lands (surface area smaller than 1 ha). These are raised bogs at 1135-1345 m above sea level. You can find here *Sphagnum compactum, S. palustre, S. papillosum, S. platyphyllum* and *S. riparium*. The common characteristic of these peat-lands is the large role of *Pinus mugo, Sphagnum russowii* and *Carex pauciflora,* and it is very interesting that *Sphagnum cuspidatum* has not been found.

In the West Bieszczady, there are 17 peat-lands. These are rather small and shallow. In this area there are so-called 'młaki' – which means the occurrence of transitory peat-land. You can find there species like *Carex* and *Eriophorum* and such interesting and rare plants as *Orchis latifolia* and *Epipactis palustris* [3].

2.3. CONCLUSIONS

The mountain peat-land is an extremely important environmental factor in headwater basins of Poland. Unfortunately, wetlands are the last relatively unchanged ecosystems in Europe, and both their area and environmental role are underestimated. Today, the main tasks are a better inventory of mountain peat-lands, a real diagnosis of their environmental role and their adequate protection. It is important to maintain peat-lands as intact ecosystems to find best protection practices. There is an urgent need to counteract global climate change and promote the more wise use of these natural resources [1].

3. Bogs Of Belarus: Geobotanical Structure, Condition and Conservation (N. Zeliankevich and I. Berniakovich)

3.1. INTRODUCTION

A total of 238 thousand ha (17 %) of modern plant cover falls within bog vegetation areas, and about 12 % does within the available land structure. Bog vegetation in Belarus has a zonal character, especially in a latitudinal direction. The entire area of converted swamplands and raised bogs makes up 562 thousand ha in Belarus: 128 thousand ha are within meliorated bogs and converted swampland areas. Raised bogs in natural conditions occupy 434 thousand ha (18% of the total area of Belarus bogs), and are thus quite expansive. Open raised bogs form 155 thousand ha (35%) and wooded bogs form 279 thousand ha (64%).

3.2. BOGS IN BELARUS

The quantity of massifs and individual small raised bogs in Belarus numbers about 1650 in all. The peculiarities of the formation and expansion of raised bogs depend on climate conditions and geomorphology of the territory. One of the determinants of the development of massifs is their nutrition, especially atmospheric precipitation where subsoil waters are inaccessible to the surface. Therefore, the expanse of raised bogs depends on coefficient moistening. This correlation is confirmed by the character of locations of raised bogs all over the Earth – in Canada, USA, New Zealand, Great Britain, Tasmania, Russia, Nepal etc. – where raised bogs are able to develop under a coefficient of moistening >1 [2].

Northern Belarus is more cold and wet compared to the south and central. Therefore, oligotrophic bogs are especially numerous in the Northern sub-zone of oak-dark coniferous forests. 73 % of bogs of this class are concentrated here. The climate conditions assist in their development in directions to the South, but the share of raised bog vegetation decreases. The area of oligotrophic massifs forms 16 % of the Central sub-zone of hornbeam-oak dark coniferous forests; moreover, they are concentrated in the East part of the territory, along with the increase in the coefficient of moistening in this direction. The coefficient of moistening goes down with further advancement to the South of Belarus and it becomes <1 in Pripiat Polesje, leading to their practical total disappearance. The nearness of the Ovruch crystalline mountain-ridge, which decreases northwest winds, is reflected in air moistening and in an increase of the coefficient of moistening to 1.2 in Mozyr Polesje, in the Southeast of Belarus. This leads to the formation of raised bogs in the Stolin and Lelchicy districts. Their area decreases in general to 4.5 % in the South sub-zone deciduous-pine forests [3].

The diversity of raised bogs in configuration and dimensions is connected with the multitude of relief forms. Oligotrophic bogs are especially various in the North subzone of oak-dark coniferous forest, which is determined by a complex combination of hilly-moraine plains, water-glacial plains, lake-glacial depressions etc. in the zones of Belorusskoje Polesje and the Belarus ridge. The relief also determines the direction of the development of bogs. The highest numbers of oligotrophic bogs are concentrated in the region of raised peat-bogs of hilly-moraine landscapes (38 %), and in the region of great raised bogs and low peat-bogs of sloping-wavy ablation plains (24 %); they are least common in the region of low peat-bogs of west final moraine landscapes (4 %) [5].

Oligotrophic bogs in Belarus can divided into two groups: open sphagnum bogs and wooded sphagnum swamps. The open sphagnum bogs occupy 155 thousand ha in Belarus (36 % of the area of this class). The following types of sphagnum-opened bogs are defined.

3.2.1. Subshrubs-Cotton-Grass-Spagnum

The growth of a rare arctoboreal species – *Betula nana* L. – is present in these bogs and therefore they are unique (Jelnia, Oswejskoje, Golubichskaja pushcha, Dolbenishki, Gryblowskij Moss, Diagilskij Moss, Clear Moss). The whole area of this type of bog constitutes about 130 thousand ha, forming 7 % of all the oligotrophic bogs of Belarus. They are practically all (95%) located in the North sub-zone of oak-dark coniferous forests.

The central association of plant communities of current bogs is Nana-Betuletum sphagnosum. The dominants and co-dominants are *Betula nana* L., *Sphagnum magellanicum* Brid, *Sphagnum fuscum* (Schpr.) Klinggr., *Eriophorum vaginatum* L., *Chamaedaphne calyculata* (L.) Moench, *Andromeda polifolia* L., *Empetrum nigrum* L., and *Oxycoccus quadripetalus* Gilib. The depth of the peat layer of this type of bog ranges from 1.5 to 2.5m.

3.2.2. Scheuchzeria-Cotton-Grass-Sphagnum

Scheuchzeria-cotton-grass-sphagnum bogs develop in suburb zones of great bog systems. This type of bog occupies 34 thousand ha; 78 % of them are concentrated in the North, while there are 14 % in the Central and 8 % - in the South geobotanical sub-zones.

The central association of plant communities is Sphagnetum scheuchzeriosum, here dominant, and the codominants are *Scheuchzeria palustris* L., *Sphafnum fuscum*, *Sph. magellanicum*, *Sph. balticum* (Russ) C. Jens, and *Sph. cuspidatum* Ehrh.ex Hoffm. The depth of the peat layer ranges from 1.5 to 3.5 m.

3.2.3. Pine-Sedge-Sphagnum

Pine-sedge-sphagnum with lake-pool-ridge vegetation complex bogs are formed in the central part of great bog massifs (Oswejskoje, Zada, Jelnia, Dolbenishki). These are the youngest and most highly water-supplied stage in the development of the raised bogs. Their whole area is 12,000 ha. The central association is Sphagnetum pineto-chordorrchizolimosocaricosum. The dominants and codominants are *Sphagnum fuscum*, *Oxycoccus quadripetalus* Gilib, *Ox. microcarpa* Turch, *Carex chordorrchiza* Ehr, *C. limosa* L., and *Pinus silvestris* f. pumila. The depth of the peat layer reaches up to 12m.

The main cover of these bogs is formed with sphagnum mosses and bushes. Pine and cotton-grass are extraordinary oppressed and thinned out here. The lake-pool-ridge complex declines toward the South of Belarus and is further forced out with a mosaic complex of vegetation.

3.2.4. Bushes-Cotton-Grass-Sphagnum

Bushes-cotton-grass-sphagnum bogs are the most expansive type of open raised bogs (179 thousand ha, or 18 % of the area of sphagnum bogs). Two basic associations of plant communities take part in the forming of cover and peat accumulation here: Magellanicum-Sphagnetum vaginatoeriophorosum and Fuscum-Sphagnetum vaginatoeriophorosum. 78 % of these classes of bogs are concentrated in the Northern sub-zone, 14 % are concentrated in the Central, and 5 % are in the South. The depth of the peat deposit is characteristically from 1.5 to 8.0 m.

Such phytocenoses, where woody a tier was reduced to the separate trees P.s. f Wilkommii Suk and f. pumila Abolin, are considerably developed on open raised bogs in addition to the aforesaid ones. Continuous moss cover consists of *Sphagnum fuscum*, *Sph. rubellum* Wils, *Sph. balticum*, *Sph. magellanicum*, *Sph. parvifolium* Warnst, and *Sph. apiculatum* Lindb. *Marchantia polymorpha* are developed on places weakly supplied with water, which leads to the forming of a peat bald spot. Such plant complexes are distributed on bogs of Belarus North: Moss, Jelnia, Dolbenishki, Skuraty.

3.2.5. Sphagnum Wooded Swamps

Sphagnum wooded swamps are presented with following typological categories. Pine-cotton-grass-sphagnum bogs are the most expanded type of oligotrophic bogs of Belarus. They occupy a territory of 185 thousand ha. The basic associations here are Pinetum vaginatoeriophoroso-magellanicoso-sphagnosum and Pinetum chordorrchisocaricoso-fusco-sphagnosum. The peat layer of these bogs develops ranges between limits 1.2 to 3.5m.

Pine-wild rosemary-sphagnum bogs occupy 93 thousand ha, or 21 % of whole area of raised bogs, or 33 % of the area of forested sphagnum bogs. The central associations are Pinetum ledoso-magellanicoso-sphagnosum and Pinetum ledoso-fusco-sphagnosum. The basic dominants and codominants are *Pinus silvestris* L., *Ledum palustris* L., *Sph.*

angustifolium, *Sph. Girgensohnii* Russ, *Sph. apiculatum* Lindb, *Sph. parvifolium* Warnst, and *Sph. centrale* Jens.

3.3. INVENTORY OF PEAT IN BELARUS

The disposition of raised bogs on the territory of Belarus is subordinated to physical and geographical and botanical zoning, which is expressed in the decrease in the area of bogs in southern direction and in the replacement of great-salient bogs with ridge-pool-complex by weakly domed bog massifs with ridge-pool-palsa complex.

The disappearance of arctoboreal plant species, and the decrease in boreal species of flora, is observed in the plant cover of Polesje bogs. *Sph. magellanicum* occupies the dominant condition in the cover of northern bogs, which changes to *Sph. fuscum* to the south [1]. The mosaic complex of vegetation, expressed in the mosaic distribution of the representatives of ridges (*Sph. magellanicum*, *Sph. fuscum*), slopes (*Sph. rubellum*), and pools in flat areas (*Sph. cuspidatum*, *Sph. palustris* L.), is typical for south bogs as well. Any raised places of microrelief are occupied with *Sph. rubellum*, but not *Sph. fuscum* or *Sph. magellanicum* as takes place on pool-ridge complexes of bogs in northern Belarus [1, 4, 5].

According to data from the Institute of Natural Resource Use and Ecology of the National Academy of Sciences of Belarus, and the newest cadastre of peat-fund, the whole stock of exposed row peat in Belarus constitutes 4398 million tons, or 25131 million m^3. At present, surveyed raised bog areas of Belarus constitute 345 thousand ha, with a stock of peat of 863 million tons (16160.7 million m^3, or 20 % of all peat reserves in bogs). The operational stocks of peat in Belarus raised bogs with layers beyond the industrial limit (1.3m and more) are estimated at 325 million tons (2431 million m^3) and with 0.7m and more are estimated at 572 million tons (4084 million m^3).

The average depth of peat in raised bogs in Belarus is 2.5 m. The area of peat layers with a depth limit of 0 is 345 thousand ha, with a limit of 0.7m and more is 247 thousand ha, and with the industrial limit is 183 thousand ha.

The characteristics of little-decomposed types of peat and peat with a large content of bitumen and carbohydrate complexes, used in bituminous and hydrolytic industries, corresponds with the general characteristics of raised bog peat on the territory of Belarus. Therefore, 55 % of weakly decomposed peat is concentrated in the entire Belarus resource. The basic stocks are concentrated in the row of the largest raised bog massifs (Jelnia, Skuraty, Dolbenishki etc.). The source of raw materials for the hydrolytic industry are those which meet the following criteria: the of decomposition is no more than 20 %, ash content is no more than 5 % of the whole (general) total resource, and stocks of peat are no less than 5.5 million tons is. A reservoir of bitumen-hydrolytic raw materials has been created in Belarus, where there are 104 million tons of peat.

The phytoproduction of raised bogs occupies a special place in the structure of plant resources. 56 % of the biological stock of all berry resources are associated namely with oligotrophic bogs. The productivity of cranberries on bogs reaches up to 2600 kg/ha (average of 200-500 kg/ha), and that of bog bilberry from 50-200 kg/ha.

In all, the quantity of raised bogs has decreased from 305 to 155 thousand ha in Belarus since 1954. The decrease in raised bog area was especially fast in the sub-zone of deciduous-pine forests, where only 15 % of this class of bogs were preserved in naturally conditions. At the present, 3.4 % of raised bogs were created, 11 % were completely drained, 56 % were partially drained, and 29 % are in natural condition [3].

For the purpose of preservation of unique plant complexes of raised bogs, their genetic fund, and diversity, a network of specially reserved natural territories has been created, which envelops under its influence 248 thousand ha (78 %) of oligotrophic massifs of Belarus. The raised bogs of Belarus are reserved on the territory of 2 preserves, 90 reserves, and 4 National Parks. In addition, 7 reserves of bitumen-hydrolytic raw materials have been created.

4. Water Balance and Wetlands in Slovenia (A. Hočevar)

In Slovenia, the annual water balance, precipitation is 31.7 cubic kilometres of water, evapotranspiration 13.2 cubic kilometres and the net outflow 18.5 cubic kilometres. In spite of these facts, wetlands do not cover large areas. According to the CORINE Land Cover classification only 0.2 % of the Slovenian area are wetlands, though together with surrounding waters the percentage of the Slovenian area is three times larger - 0.6%. Slovenia's list of wetlands includes more than 3500 locations but less than one third of them cover more that 0.15 ha and these cover 1.74 % of Slovenia. Even if all flooded areas are included, this is still under 5% of the total Slovenian area, with the latter of these mostly flooded or wet meadows.

In Slovenia, the wetlands are one of the most menaced ecosystems. According to the Ramsar Convention (1971), there are 9 types of maritime and shore wetland, 17 types of land wetland, and 8 anthropogenic type

[1]. Despite these numerous and variety, they are usually small and therefore very susceptible to changes. Many have disappeared due to agriculture expansion, especially those close to the sea and along the rivers and which flood due to ample precipitation.

Concerning the protection of wetlands, it is best when they are a part of existing or planned protected areas viz. natural parks, included in the net NATURA 2000, or included in as a part of internationally important wetlands according to the Convention about wetlands (Ramsar 1971). In Slovenia there have legislation for that purpose [2]. Despite the fact that Slovenian wetlands do not cover large areas of the country, they are still considered important.

5. Headwater Wetlands in Canada (G. P. Kershaw)

Canada is blessed with fresh water resources amounting to 20% of the world's fresh water and 7% (105,000 $m^3 s^{-1}$) of the world's renewable fresh water. Almost 9%, or 891,163 km^2, of Canada's total area (9.98 10^6 km^2) is covered by fresh water. Wetlands cover 14% (1.48 10^6 km^2) of the country and this amounts to 25% of the world's wetlands. The bulk of Canada's drainage (60%) flows north and northern wetlands are affected by permafrost. There are 10 provinces and 3 territories in Canada with legislation differing among the jurisdictions. Federal laws apply to the entire country especially as they related to international and inter-provincial waterways, fisheries, waterfowl, and transportation. In northern Canada devolution of powers to Territorial Governments and local Renewable Resource Boards has followed the settlement of native land claims. These developments are ongoing and in a state of flux.

Permafrost landforms such as palsas and peat plateaux occupy extensive areas in northern Canada. In the study area permafrost warming by 1ºC has occurred during the past thirteen years while over the same period air temperatures have cooled or remained stable. As determined by ground penetrating radar and coring, depth of permafrost in wetlands/peatlands can exceed 12 m. If the permafrost thaws the liquid water storage capacity will increase. In the study area this can result in as much as a 60% increased capacity and retention times. This could result in reduced peak flows following snowmelt and high rainfall events. It could also increase year-round base flows in affected drainage basins.

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HEADWATER AND WETLAND PROTECTION:
The Italian Legal Framework

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***KEYWORDS / ABSTRACT**: Headwaters / wetlands / protection / legal framework / Italy*

The framework of Italian legislation affecting the conservation of headwater wetlands has developed within the wider context of landscape and cultural conservation and without special reference to conditions in headwaters.

1. Introduction

In Italy, the environmental protection legal framework has grown up within the wider context of landscape and cultural heritage conservation. The first protected areas were established around 1933, within the wildest mountain areas (Stelvio, Gran Paradiso, Abruzzo). Subsequently, in 1939, two landscape protection acts addressed the nation's most historical, cultural, monumental and panoramic sites.

In 1985, the whole legal framework was amended by introducing general "landscape value constraints" (glaciers, wetlands, watercourses or above 1600 m mountain areas), to be detailed by proper Landscape Regional Plans. All these protecting measures have been coordinated, in the framework of the 1999 Landscape General Reform, by linking cultural heritage protection with the defence of landscape environmental values.

2. Ramsar Convention

In 1976, the Italian Parliament signed the Ramsar Convention. However, a systematic strategy for environmental protection has been in place only since 1986, thanks to the formal institution of the Ministry of

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Environment. Since then, several new laws have been referred to this administration and some affect with headwater and wetland protection:

- 1986 Nature Charter - coping with international conventions such as Ramsar;
- 1991 Protected Areas Act - establishing new national parks and nature reserves;
- 1999 Decree on water quality - addressing water quality protection within vulnerable areas.

3. Soil and Water Management Legislation

Between 1999 and 2002, the Ministry of Environment took over responsibilities formerly assigned to the Ministry of Public Works, including the soil and water conservation duties. These duties are based on the following major acts:

- 1923 Decree - introducing "hydrological constraints" to avoid woodland and land use transformations affecting soil stability or increasing floods risk;
- 1989 Soil Defence Framework - establishing the integrated management of both soil and water resources in the framework of Watershed Management Plans, and the institution of national and regional Water Basin Authorities;
- 1994 Water Act - affirming the public property of all water resources to protect their prior use for drinking water and environmental purposes;
- 1998 "Sarno" Decree - advocating the effective implementation of Floods and Landslides Risk Areas Plans by April 2001.

4. Current Developments

Recent reform has led to a new Ministry of Environment and Territory, and to a general reorganization of institutional assignments at national and local levels under the 1998 Decentralization General Scheme Act. Regional bodies are now frees to set their own priorities in urban and land use planning, local biodiversity, water quality, landscape management, and forestry programs, forest fire risk prevention, mountain areas incentive schemes, and rural development support.

Recent EU Directives concerning headwater or wetland management, such as the Soil Strategy of the Sixth Environmental Program OM(02)179 and the Water Framework Directive 00/60 have yet to be incorporated by Italian regulations.

NEXT GENERATION OF WATERSHED MANAGEMENT PROGRAMMES:

Objectives and Expected Results

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KEYWORDS / ABSTRACT: Integrated watershed management / mountains / conservation / highland-lowland relationship / participatory programme

As a result of increasing population, which has doubled every 25 to 30 years during the twentieth century, pressures on upland resources have increased and watershed degradation has become a worldwide concern. Watershed degradation effects have represented a serious threat not only to the environment but also to the survival of millions of people living in upland as well as downstream areas. Recognizing the importance of upland areas conservation, especially in most developing countries whose economies is depend predominately on agriculture, watershed management has received over the last few decades increasing attention from countries themselves as well as from concerned international and regional organizations. It is clear that much progress has been achieved in watershed management, especially during the period of 1990-2000, where new approaches and methodologies were developed to promote participatory integrated watershed management. However, no clear picture has been drawn on what has been really working and what can be done to improve future watershed management programmes. The latest systematic effort to review and assess watershed management strategies and approaches at a global scale was conducted 18 years ago. It was carried out by FAO through the Expert Meeting held in Kathmandu, Nepal in 1985. Hence, in-depth analysis of watershed management achievements and existing gaps, with particular emphasis on the 1990-2000 experiences, is a prerequisite to further development of watershed management programmes.

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1. Introduction

Interest in and awareness of the multiple environmental, economic and social benefits provided by watershed management and development has greatly increased in recent decades. This may be particularly true in developing countries where the economy is depending predominately on agriculture. It is generally accepted that sustainable use and management of land resources will only be achieved by adopting a system of improved land, water and vegetation management and use, based on an integrated approach for land resources development with direct involvement and participation of the different actors. Given that watershed management is the implementation of management systems which ensure the conservation and sustainable use of all land resources, the development of watershed management is being recognized as a pre-requisite for the sustainable management of the upland-lowland resources as well as for the improvement of the living conditions of upland inhabitants.

In spite of substantial achievements in the field of watershed management, reversing watershed degradation still requires long-term commitment and vision from governments and concerned stakeholders. In response to emerging key issues of major concern to the development of watershed management, the review and assessment of watershed management activities intending to provide reliable information on lessons learned and existing gaps are considered as an urgent need.

2. Why Focus on Watershed Management?

> *"Promoting integrated watershed development programmes through effective participation of local people is a key to preventing further ecological imbalance. An integrated approach is needed for conserving, upgrading and using the natural resource base of land, water, plant, animal and human resources"*
> Chapter 13, Agenda 21, UNCED [8].

The main aim of watershed management is to conserve the soil, plant and water resources of a catchment while benefiting humanity. This means managing both land and human resources in ways that will sustain water, soil, food and fibre production. Watershed sciences include various aspects of forestry, agriculture, hydrology, ecology, soils and climatology.

But those involved in managing watersheds must also be aware of the many different environmental, economic and social factors that come into play, so that the maximum benefits can be achieved while producing the fewest negative effects possible.

In this context, it is widely accepted that the use and management of land, water and vegetation must take an integrated, participatory approach if they are to be sustainable. Given that watershed management is the implementation of management systems which ensure the conservation and sustainable use of all land resources, integrated watershed management through people's participation has become widely accepted as the approach which ensures sound sustainable natural resources management and a better agriculture economy for upland inhabitants as well as people living in downstream areas. In addition, the watershed management approach is well suited because it includes all the implications and interactions between upstream and downstream areas. In addition to the technical aspects, it also takes into account the ecological, social and economic dimensions in order to ensure that all land resources are conserved and used sustainably while the living conditions of upland populations are improved. It is a fact that the watershed condition of topography, soil, vegetation and land use has direct implications on the water resources in general and on the behaviour of the natural resources in particular.

3. Achievements and Existing Gaps in Watershed Management

Realizing the importance of the conditions of upper catchments, reversing watershed degradation became one of the priorities for many countries, particularly during the 1980s. However, many watershed management programmes carried out during that period have failed to achieve their objectives mainly due to the following reasons:

- The programmes were too focussed on natural resources conservation.
- The programmes were designed with little attention to human activities and to the priorities and needs of people or too focussed on the poor farmers and subsequently achieving minimal economic and environmental impacts.
- The programmes neglected the involvement of beneficiaries and their contribution in the planning and implementation of the watershed management interventions.

- Projects were frequently limited in span and scope and lacked long-term commitments needed to address underlying causes and long-term management issues in a satisfactory way.

Consequently, new concepts and approaches were developed. Recognizing that management and conservation of land resources through physical structures, reforestation and other conservation measures would not be sustainable and replicable unless the priority concerns of local communities were taken into account, the integrated concept was further developed as a process where community problems and needs could be considered as an important component of the development of watershed programmes. Watershed management has become a multi-disciplinary activity where appropriate institutional and organizational mechanisms are required for coordination/implementation of watershed management activities.

The development of concepts and approaches and watershed management experiences carried out in many places of the world now calls for further investigation, analysis and consultation among stakeholders in watershed management, for greater understanding of what has been achieved and how new programmes could be improved.

Many stakeholders are stressing the need to have a clearer picture on several key issues of major concern to watershed/uplands management. The increased attention to mountain issues by countries during the International Year of Mountains has resulted in greater emphasis on the importance of developing national strategies for the sustainable development of mountain areas within a multi-disciplinary, multi-stakeholder and long-term framework. The Task Manager report on Chapter 13 [8] emphasized the highland-lowland relationship and the need to develop compensation mechanisms for environmental services and goods provided by mountain watersheds.

4. Some Emerging Key Issues

As a consequence of the attention given and important investments secured for the development of watershed management, much progress has been achieved in the development of innovative approaches. However, several issues of major concern, some of which were raised many years ago, still require in-depth analysis and consultation among all concerned parties for better understanding and implementation of effective watershed management.

A quick overview of findings and recommendations of reviews of watershed management activities over the last decade outlines a number of key issues:

- Are we sharing experiences and lessons learned? It is recognised that significant progress on watershed management approaches and methodologies has been achieved in different places of the world. However, sharing these results and identifying the appropriate mechanisms for the dissemination of such information are important issues which require urgent action in order to benefit the design of new projects and avoid repeating failed approaches and mistakes of the past.
- Are we using the appropriate participatory processes? The experience with participatory approaches during the last decade has raised several related issues, such as: what kind of participation is taking place? To what extent can the participatory approaches be used and replicated? Are we overestimating what can be achieved through participatory approaches?
- Are the developed technologies producing the desired results? Greater emphasis is being put on the services and benefits that watershed management can provide. Watershed management is increasingly seen as an appropriate vehicle not only for environmental conservation but also for the improvement of living conditions in rural communities. In this regard, there is a need and increasing demand for the development of appropriate technologies which can ensure sustainable development and natural resources management.
- To what extent can forests/forested watersheds play a role in sustaining and protecting water supplies? Although this issue is still under discussion and debate, many believe that the watershed perspective is the best framework where forest hydrology impacts can be better understood and translated into effective programmes of sustainable management of water resources.
- Are project activities sustainable and replicable? There is uncertainty about the sustainability and replicability of technologies and activities developed and implemented by projects. On this issue, the World Bank report [9] of the review and assessment of watershed management projects has raised this

concern, stating that "many Bank projects, while able to achieve considerable gains in the short-term as a result of an intensive injection of funds and expertise, are neither replicable nor sustainable following project completion".

- To what extent have adequate institutional/organizational and legislative arrangements been developed? Institution building for watershed management has been raised as one of the most neglected parts of watershed projects. In this respect, it is being recognised that there is a need for improved understanding and identification of institutional and organizational arrangements required for effective watershed management. An appropriate legislative framework to support watershed management policies has also been raised as an important tool which needs particular attention.
- Are the required policies/strategies in place? Recent relevant assessments have shown that although broad environmental policies are in place in many countries, generally no attention has been given to the development of watershed management policies. The lack or inadequacy of national policies, strategies and action plans are recognised as principal constraints to implementing sustainable watershed management programmes.

5. Towards Effective Watershed Management

Watershed management offers the possibility to consider the interrelationships between the productivity and conservation in the use of natural resources as well as the recognition of upstream-downstream linkages related to the protection and use of land resources, especially with regards to water supplies. Kerr [5] outlines that a watershed or catchment is an area from which all water drains to a common point, making it an attractive unit for technical efforts to harness scarce water resources and conserve soil for agricultural production and natural resources conservation.

With the water scarcity issue increasingly recognized, watershed management has become widely accepted as the approach best suited for sustainable management of water resources both in upland and downstream areas. To better consider the opportunities offered by watershed management and the challenges and constraints it faces, efforts are needed to develop innovative approaches to cope with emerging issues and controversies such as the threat of water scarcity and the role of forest hydrology in the sustainable management of water resources.

In order to achieve effective watershed management, it is of major importance to examine the state-of-the-art of watershed management programmes and concepts. In this context, FAO launched in early 2002 [3], in the framework of the International Year of Mountains (IYM) 2002 [4], the initiative "Preparing the Next Generation of Watershed Management Programmes" to review and assess watershed management activities. The review aims to:

- provide an adequate opportunity/platform to all concerned parties to share information and contribute to a better understanding of the current status of watershed management;
- provide required advocacy and support for the implementation of effective watershed management at local, national and regional levels.

The review was conducted in close collaboration with a large number of partners/key actors in watershed management. A questionnaire was prepared and sent to an identified list of 30 key actors in watershed management to provide relevant information for the review. The responses were reviewed and summarized in the context of the major topics of the review.

To achieve the review's objectives, five steps were identified as necessary: first, to identify and involve key actors in watershed management; second, to conduct stocktaking of FAO experience in watershed management; third, to analyse selected case studies on watershed management projects or programmes; and fourth, to convene a series of regional workshops for partners/stakeholders input. The fifth step is the organization of an international conference where the results of this process are shared and discussed among key actors in watershed management. The final step consists in the formulation of guidelines / strategies for effective watershed management programmes and distribution of results on a global scale.

6. Elements of Next Generation Watershed Management Programmes

In spite of the progress achieved in developing watershed management approaches and their application, conflicting views on the approaches and methods of watershed management and controversies over issues of major concern, such as people's participation, upstream-downstream linkages and required institutional arrangements are calling for further analysis and identification of the appropriate elements which constitute effective watershed management. In this respect, the following elements are considered by many as needed to achieve effective watershed management:

- Scale effects: Although, it is easier to monitor watershed management effects at smaller scale, watershed management activities should be considered at the local, national and regional levels. Successful cases are not limited to small size watersheds. The benefits of watershed management for freshwater supply are better recognized when the upstream-downstream linkages and interactions are linked to scale effects.
- Stakeholders involvement/participation: In addition to the participation of upland communities as a key factor in the success of watershed management programmes, all stakeholders, including downstream users of watershed resources, appropriate government institutions, NGOs and other concerned parties should be involved from the very beginning in watershed management programmes. Such involvement and participation should be integrated as a major component in the design / development of relevant programmes and policies.
- Special emphasis on water: To deal appropriately with water resources management, effective watershed management requires innovative approaches and adequate technologies. Taking into account events such as the International Year of Mountains 2002 and the International Year of Freshwater 2003, the application of forest hydrology should be considered as one of the important elements constituting effective watershed management.
- Economic returns: To ensure sustainability and enhance the potential for successful replication of watershed management interventions, greater attention is needed to ensure that economic returns to upland populations who are managing watershed resources are fully considered and maximized. This will also benefit downstream inhabitants who benefit from improved upstream management. In this respect, the initiatives launched on the payment for environmental/hydrological services should be enhanced.
- Adequate institutional/organizational arrangements: There is increasing recognition of the need for improved understanding and identification of institutional and organizational arrangements

- required for effective watershed management, including appropriate legislative frameworks to support watershed management policies.
- Long-term vision/commitment: Watershed management is increasingly seen as an appropriate vehicle not only for environmental conservation but also for the improvement of living conditions of rural communities. In this regard, there is a need for long-term commitment from all stakeholders, including adequate and sustained financial investment.

7. Conclusions and Recommendations

Although watershed management activities have contributed significantly to reducing land degradation and improving the quality of life and livelihood opportunities for many people throughout the world, the real potential of watershed management has yet to be realised. Factors such as outdated approaches, poor project design, inadequate and/or un-sustained financial resources, very short time frames for project interventions and a lack of adequate understanding of the linkages between upland and lowland areas have contributed to under-achievement of watershed interventions. However, during the last decade in particular, new and innovative approaches to watershed management have been developed which have demonstrated better results and show promise of bringing about long term and sustained positive change with respect to environmental, social and economic conditions.

Unfortunately, little effort has been made to take stock of these new and promising approaches and to consolidate lessons learned for the future design of watershed interventions. In view of the issues mentioned above, an assessment and review of achieved results and lessons learned in watershed management are considered as a prerequisite not only to provide answers and clarifications on the emerging issues but mainly as an important preparatory stage for the next generation of watershed management projects and development programmes.

To better consider the opportunities offered by watershed management and the challenges and constraints it faces, new and improved efforts are needed to develop innovative approaches to cope with emerging issues such as water scarcity and how forest hydrology can more effectively contribute to the sustainable use of water resources. Based on an in-depth analysis of watershed management activities carried out over the last few decades, with emphasis on the last decade (1990-2000), and taking advantage of opportunities provided by the International Year of Mountains 2002 and the International Year of Freshwater 2003, guidelines for future watershed management programmes are being developed taking into account achieved results and existing gaps in watershed management. In this respect, the following recommendations made at the International Conference "Integrated Watershed Management: Water Resources for the Future, Sassari Province, Italy, 22-24 October 2003", where the findings of the review and assessment of watershed management activities were analyzed, highlight the need for innovations in implementing future watershed management programmes:

- There is a need to focus increased global and regional attention on watershed management because watersheds integrate resources, environmental services and uses and users.
- Based on the review outcome, develop a set of guidelines for the next generation of watershed management programmes that can be applied to the design and screening of new projects.
- Some of the key elements of the guidelines for the next generation of watershed management programmes include: a multi-sectoral approach; a combination of bottom-up and top-down planning, monitoring and evaluation; clear procedures for environmental impact assessment of interventions including dams and reservoirs; networking among key stakeholders; consideration of socio-economic and cultural aspects and natural processes; gender balance in decision making; embracing new approaches for sharing knowledge and learning; sustainable finance; compensation mechanisms; capacity building at all levels; reforming governance, linking surface, groundwater and coastal water sources; shift from looking at supply to demand of water; efficiency of water use; coping with hydrologic extremes and natural hazards; and the integrated management of water, vegetation, soils and sediments.
- Guidelines for the next generation of watershed management programmes should be tested and demonstrated in pilot cases, with planning and implementation from local, national and transnational scales.
- Considering the need for integrated approaches to watershed management, donor agencies, financial institutions, government departments, civil society organizations and the private sector

should commit to long-term inter-sectoral and innovative planning, finance and execution of watershed management.

- Because watersheds often span political boundaries, watershed management should be seen as an integrative approach that has value in understanding and resolving conflicts between upstream and downstream communities and countries.
- Because rural and urban poverty is a significant contributing factor to watershed development and degradation, the multiple linkages between poverty and watershed management should be better understood and considered in the planning of both watershed management and poverty alleviation programmes.
- It is recognized that there is an urgent need to build capacity of all stakeholders (including watershed inhabitants and professionals at local and national levels) to understand and manage the multi-sectoral processes and approaches necessary for effective watershed management.
- Presently land and water governance institutions and policies are often inadequate to support the integrative and multi-sectoral approach needed to implement watershed management. It is therefore needed that: (1) institutions for integrated basin management be established and strengthened with appropriate legal status, resources and financing; (2) there be more effective and equitable communication among local communities, managers and policy makers; and (3) policies be based on clear evidence and tested principles.
- Considering that the management over land and water resources is highly fragmented at all levels, consideration should be given to the establishment of an international forum that focuses on integrated watershed management including land use and human activities that impact water.

By systematically reviewing both successes and failures in watershed management interventions in recent years, watershed management programmes will be more effective at reducing environmental degradation and improving the lives of the rural poor in a long term context. Additionally, through better design and fuller and more integrated consideration of both upstream and downstream concerns, future interventions should be able to have greater overall benefit through a more balanced approach that includes a major focus on the sustainable use and conservation of water resources.

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CONCLUSION – WETLANDS IN CONTEXT

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Hitherto, wetland research has focused more on the internal attributes of wetlands than on the role of wetlands in wider watershed contexts. It has also concentrated on coastal and floodplain wetlands more than those in headwaters, many of them peatlands, which have greater hydrological significance through potential downstream impacts. Previously, headwater wetlands have been valued mainly for their land use conversion potential. Recently, it has become recognised that these lands provide many valuable environmental services. They influence flood flows, sediment loads, and aquifer recharge; biochemical water qualities and biodiversity. They provide water, peat, timber, grazing land and, locally, aesthetic, cultural, recreational and educational benefits to local communities. Better environmental understanding is required to maximise their benefits to stakeholders and minimise potential negative impacts due to climatic emissions of greenhouse gases, hydrological changes (especially flooding, water chemistry, and sediment release). Towards this end, a new and comprehensive inventory of headwater watersheds is urgently required. Research also needs to be reoriented to focus on the tolerances, exchanges, checks and balances within headwater landscapes and the downstream impacts of changes in wetlands. There is a need for better data, especially from longer-term environmental monitoring, for better management models and for a greater sharing and utilisation of existing information. The effective management of headwater wetlands requires new policy frameworks, changes in land husbandry, more sensitive technological intervention and the full integration of wetlands into environmental management planning. It also needs better systems for community education and more effective participatory processes

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1. Introduction

The management of watersheds that contain significant areas of wetland, especially in the upper catchment and headwaters, presents an important practical problem for environmental managers. Much current research into wetlands is difficult to apply in watershed management. Hitherto, wetland research has tended to focus on the internal attributes of wetlands – as resources for wildlife biodiversity, economic development or hydrological regulation – more than the role of wetlands in their wider watershed contexts [41].

The extent of headwater wetland is significant. An assessment of headwater wetland areas was carried out for the EU15 Countries (excluding Sweden) plus Poland, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, Bosnia and Herzegovina, Albania, Macedonia. Here, CORINE data suggests that headwaters amount to 1,000,000 ha (27%), and wetlands in headwaters to 10,600 ha, which is about 1% of the headwater area (Paracchini and Vogt, this volume).

However, in some nations, not least Russia, Belarus, Canada, the Nordic and Baltic countries, the situation is very different. In Canada, which has perhaps 25% of the world's wetland area, wetlands cover more than 14% (1.48 10^6 km^2) of the land surface (cf. Markova et al., this volume). In Russia, 15% of the land surface is wetland (including 1.8 10^6 km^2 of mires and 1.5 10^6 km^2 of forested peatlands), while more than 20% of the area of Estonia is marshland and bog [38]. In Poland, peatlands cover only 1.3 10^6 ha (4.2% of the territory) but 75% occur in the north (Markova et al., this volume). However, in the former USSR, which included 70% of all of the world's peatlands, peat bogs covered between 9-9.5% (>2.0 10^6 km^2) of the total territory [39].

The extent of these lands decreased, dramatically, in nearly every one of their original locations. Traditionally, headwater wetlands have been regarded as land that is best converted to more economically productive uses; reclaimed through drainage, forestation and agricultural development. In the USSR, $0.08*10^6$ km^2 of peatland was reclaimed before 1953 [39]. In Belarus, around $0.05*10^6$ km^2, (25% of the country) is covered by peat and marshland (Markova et al., this volume). Goloubovsky [10] comments that, while originally, mires covered 14.2% of the land area of Belarus ($0.03*10^6$ km^2), the huge drainage and ameliorative campaigns in the period 1950 - 1990, reduced the area by

>60% to just $0.009*10^6$ km^2. A seventh of Canada's original wetlands have also been converted to other uses (Markova et al., this volume). Today, the intrinsic properties of headwater wetlands are more valued. Several nations, including the UK, are trying to prevent further land conversion and, locally, some are seeking to reclaim wetlands by closing off drains (cf. Haigh, this volume).

This volume focuses on a special category of wetland, those that are found on the upstream margins of river systems, the headwater regions. In hydrological terms, headwaters are zero to first order catchments; the lands where water flow-lines originate. They are very major landscape features. A pioneering GIS survey estimated that headwater areas cover 41-58% (1,334,612 - 1,878,433 km^2) of the European Union (2000) [29]. This, some say 'surprisingly', great extent recognises the fact that river systems are branching systems with fractal attributes. Streams of every stream order have headwaters. Headwaters are found on the upper margins of every stream catchment at every scale. The River Nile has headwaters and so does its every tributary down to the very smallest. Again, headwater areas are always found on the highest parts of their particular catchments. However, the EU (JRC) team found that headwaters are evenly distributed with respect to altitude [29]. So, major headwater areas are found in mountains and highland areas but, equally, important headwater areas are found on the uppermost margins of lowland river and stream systems.

The essential characteristic of a headwater is that it is both a margin between catchments and a point of origin for stream flow. These lands provide the recharge zones for both surface and ground waters. They form the margins of hydrological (and often socio-economic) systems. Frequently, they are also frontiers of development. At almost every scale, headwaters can become wracked by conflict concerning the exploitation of natural resources, tourism, nature protection and political control. This is why adverse conditions in headwater regions can have dramatic effects on both the environmental and political stability of areas downstream.

Headwater wetlands are special headwater environments. For many years, they have been granted little value, recognised mainly as areas with a potential for land use conversion. More recently, it has begun to be recognised that headwater wetlands and peatlands can provide many valuable environmental services. They influence flood flows, sediment loads, and aquifer recharge; biochemical water qualities, and biodiversity through the special habitats they provide [47] (Balek, this volume). They provide water, peat, timber, grazing land, and locally aesthetic, cultural, recreational and educational benefits to local communities (Haigh, this volume; Hama et al., this volume). They may also have a role in buffering climate change, through carbon sequestration [20]. However, in general, the value assigned to headwater wetlands by national and regional planning agencies, for anything apart from nature conservation, remains very limited.

2. The Mandate: Nairobi Declaration for the International Year of Freshwaters 2003

This problem, the undervaluing of headwater wetlands, was identified, originally, by delegates at the *International Conference on Sustainable Management of Headwater Resources,* (The Fifth International Conference on Headwater Control, Nairobi, 2002) [22]. The major output of this conference, which conceived itself as a 'break-out' group from the United Nations WSSD Conference in Johannesburg, was the *Nairobi Declaration for the International Year of Freshwaters 2003,* which was ratified by six United Nations agencies [21]. The Declaration's Item 18, which advocates that greater attention needs to be paid to the special roles and hydrological functions of headwater wetlands and peat lands, also argues that this should be a special focus for future headwater workshops. This provided the mandate for the organisation of this NATO Advanced Research Workshop, convened in Marienbad, Czech Republic with major assistance from the International Association on Headwater Control [11]. The complete text of the Nairobi Declaration follows as Box 1.

Box 1: Nairobi "Headwater" Declaration for the International Year of Freshwater 2003 [11, 21.

We, the participants in the International Conference on Sustainable Management of Headwater Resources, held in Nairobi (Kenya) on 5-8 September 2002,*

1. Acknowledging with gratitude the United Nations General Assembly Resolution No. 55/196 to declare the year 2003 as the International Year of Freshwater, thus drawing the world's attention to the need to foster sustainable development and management of freshwaters;
2. Noting the outcome of the recent World Summit on Sustainable Development in Johannesburg 2002, where commitments were made "to increase access to clean water and proper sanitation, to increase access to energy services, to improve health conditions and agriculture, particularly in drylands, and to better protect the world's biodiversity and ecosystems";
3. Recognizing that headwater regions are sensitive environments, source areas for both surface and groundwater resources, and lands that affect the quality of freshwater

supplies;

4. Keeping in mind that headwater regions lie at the margins of both watersheds and, often, social and economic systems;
5. Recognizing also the critical environmental functions of headwater regions and their importance for the livelihoods of both their inhabitants and for those who inhabit lands downstream as evoked in Chapter 18 *"Protection of the quality and supply of freshwater resources: application of integrated approaches to the development, management, and use of water resources"* of Agenda 21 adapted at the United Nations Conference on Environment and Development (1992), and also as stipulated in its Chapter 13 entitled *"Managing fragile ecosystems: sustainable mountain development";*
6. Affirming our concern to mitigate the consequences of the increasing human impact in headwater regions caused by competing demands for water, forestry, agriculture, energy production, tourism, transport and urban development, which continue to affect the environment adversely, not least with respect to the provision of clean water supplies and the maintenance of other hydrological functions;
7. Noting with further concern that policies can impair, seriously and inadvertently, the course of headwater resources management, and that this can create problems downstream for the quality, quantity and distribution of available freshwater resources;
8. Recognizing that sustainable management of headwater regions needs a holistic, integrated approach which respects the needs of all stakeholders in the regions, values and empowers the headwater inhabitants, and which recognizes their central role in the stewardship of headwater systems;
9. Affirming that the sensitive and scientific management of natural resources, supported by improved access to the high quality data required is essential for fostering development that is not only sustainable, but ideally self sustaining;
10. Conscious that unsustainable management has negative impacts on the health, productivity, social and economic welfare and ecosystems of headwater regions;
11. Aware of the increasing demand for potable waters that will be required for human health, welfare and well-being, and of the crucial role that headwater regions will play in meeting this demand;
12. Conscious also of the potential negative interactions between the inhabitants of headwater regions and those downstream, caused by competition for the limited resources available in the regions, and aware also that headwater areas accommodate and provide for livelihood of a large number of populations, whose activities and resources consumption may have significant effects on the well-being of those who live downstream;

Declare that:

13. Sustainable development should be the baseline for all environmental policy, planning, management practice, education and law in headwater regions;

14. UN agencies should continue their work with all stakeholders to appraise their situations, to identify gaps in knowledge, needs and constraints, and to support them in their efforts to resolve their problems and undertake practical action towards more self-sustaining and environmentally sensitive development;

15. An 'international commission' for headwater management should be established in

order to provide direction and continuity for headwater issues and to create an awareness of headwater concerns at governmental level;

16. Priority should be given to the creation of new management structures at all levels, which should be designed to improve the coordination, cooperation and empowerment of all stakeholders of headwater regions, not least to enhance the participation of women, disadvantaged social groups and minority communities, and to tap and develop the full spectrum of local indigenous knowledge relating to watershed planning and management;

17. Greater effort should be devoted to the refinement of methods for generating and sharing the appropriate and reliable information needed for environmental research, planning and management and also for the transfer of appropriate low cost technologies, especially with respect to 'cushioning' the impacts of environmental hazards for human populations;

18. Greater attention needs to be paid to the special roles and hydrological functions of headwater wetlands and peat lands, which should be a special focus for future headwater workshops, and also to the impacts of anthropogenic processes on watershed functions in headwater regions;

19. The quality of life for the inhabitants of headwater regions should become a primary concern, including the basic needs for a healthy environment and the regeneration of degraded headwater habitats where required;

20. Greater attention should be paid to applied environmental education aimed at building capacity for headwater management and changing social attitudes against wasteful and polluting uses of headwater resources;

21. NGOs (community-based non-governmental organizations devoted to environmental and/or social uplift) should be empowered to play a greater role in the planning, regeneration and management of headwater habitats, by promoting more efficient mechanisms for financial support for effective NGOs;

22. Greater attention should be given to management of headwaters in arid and semi-arid lands, especially with respect to groundwater management and improved accessibility of potable waters to headwater inhabitants, while the one of the main focuses should be to reduce the time wasted in carrying water to households from distant water sources;

23. Attention should also be paid to alternative measures that would reduce the dependence of downstream areas on the resources of headwater areas, including reducing wastage and increasing the efficiency of resource utilization, not least of water;

24. The equitable distribution and use of headwater resources remain a major concern, and planning and management of headwater regions needs to be integrated within the broader framework of watershed management that addresses the concerns of both headwater inhabitants and those downstream.

We therefore call upon UNU, UNESCO, UN-HABITAT, FAO, UNEP, UNDP and other concerned international and national organizations, governments of both developed and developing countries, corporations and NGOs, to facilitate headwater research, monitoring, capacity-building, self-sustaining sustainable development, and better management of the headwater environments, and to help create linkages and synergies in this regard among environmental managers, scientists, communities, policy/decision-makers, practitioners and the general public.

*This conference, which took place from 5-8 September 2002 at the United States International University – Africa in Nairobi, Kenya, was jointly organized by the United Nations University, Tokyo, Japan, UNESCO-Nairobi, the United Nations Centre for Human Settlements (UN-HABITAT), the United Nations Environment Programme (UNEP), USIU and Kenyatta University, Nairobi, Kenya, in collaboration with International Association for Headwater Control (IAHC); International Association of Hydrological Sciences (IAHS); and the World Association for Soil and Water Conservation (WASWC).

3. Role of Headwater Wetlands in Africa

The *International Conference on Sustainable Management of Headwater Resources* was convened in Nairobi and, naturally enough, had special concern for the situation in sub-Saharan Africa. The total area of Africa's wetlands has been estimated at $0.34*10^6$ km^2 (Balek, this volume). Workers in this region, point out that, while much attention has been devoted to the impacts of deforestation and poor land husbandry on runoff, erosion and water qualities, relatively little attention had been given to the role of wetlands within headwater areas [7, 47]. However, the environmental services these wetlands provide were thought to include storing water through the dry season, regulating stream flow, reducing floodwater peaks, improving water quality and sustaining human livelihoods [8, 28]. In the Nile headwaters, where land degradation has reduced the capacity of many lands to store water or regulate runoff, the hydrological role of wetlands had become increasingly important (Wood, 2006).

Although generally small in area, such wetlands ('dambos', 'igishanga', etc) also provided key resources for local communities [47]. Indeed, in Rwanda, the rational systematic exploitation and development of the nation's $1.65*10^3$ km^2 of wetland (i.e. 6% of the national area, (cf. Kenya 2-3%) [9] - especially that in the larger marshes, is seen as a key opportunity for national development [46]. Wood [47] introduced the following table as a summary of the various functions that these wetlands provide (Table 1).

FUNCTIONS	PRODUCTS	ATTRIBUTES
• Water storage	• Forest resources	• Biological diversity
• Groundwater recharge	• Wildlife resources	• Uniqueness to culture
• Groundwater discharge	• Fisheries	
• Flood control	• Forage resources	
• Sediment retention	• Agricultural resources	
• Nutrient retention	• Water supply	
• Biomass export		
• Micro-climate stabilisation		
• Water transport		
• Recreation / Tourism		

Table 1: Wetland functions, products and attributes [8. 47].

In discussion, at the conference's plenary and break-out sessions, several questions arose; not least the question - why are these African wetlands so neglected by national and land use planners [7, 46]? Among the suggestions were: 'they occupy relatively small areas in most basins', most had been regarded hitherto as 'land suitable only for drainage and reclamation', their hydrological roles and functions were unknown or contested (vide. Balek, this volume; Wood, this volume) and because of the 'negative impact' of the Ramsar Convention, which had 'focussed international attention on the internal properties of wetland and on their role in wildlife conservation' to the exclusion of much else.

4. Ramsar Convention (1971) – No Longer 'Strictly for the Birds'?

The Ramsar Convention is the main international treaty that deals with the conservation and management of wetlands. The "*Convention on Wetlands of International Importance especially as Waterfowl Habitat"* was created in Ramsar (Iran) in 1971 but has been much updated subsequently [43] (Box 2). Currently, 144 partners to the Convention recognise 1421 'Wetlands of International Importance' covering almost 124 million hectares [32]. The Ramsar website opens with a quotation about its mission, which is: *"the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world"* [6].

However, Article 2.2 of the Ramsar Declaration remains as follows: *"Wetlands should be selected for the list on account of their international significance in terms of ecology, botany, zoology, limnology or hydrology. In the first instance wetlands of international importance to waterfowl at any season should be included"*. Article 4 also focuses on waterfowl and wetland wardening, while articles 5 and 6 stress the conservation of the wetland's own flora and fauna.

Box 2: Prefatory Arguments of the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar, Iran, 2.2.1971; as amended by the Protocol of 3.12.1982 and the Amendments of 28.5.1987. **Certified copy** Paris, 13 July 1994; Director, Office of International Standards and Legal Affairs, United Nations Educational, Scientific and Cultural Organization) (http://www.ramsar.org/key_conv_e.htm - accessed February 2005)

- RECOGNIZING the interdependence of Man and his environment;
- CONSIDERING the fundamental ecological functions of wetlands as regulators of water regimes and as *habitats supporting a characteristic flora and fauna, especially waterfowl;*
- BEING CONVINCED that wetlands constitute a resource of great economic, cultural, scientific, and recreational value, the loss of which would be irreparable;
- DESIRING to stem the progressive encroachment on and loss of wetlands now and in the future;
- *RECOGNIZING that waterfowl in their seasonal migrations may transcend frontiers and so should be regarded as an international resource;*
- *BEING CONFIDENT that the conservation of wetlands and their flora and faun***a** can be ensured by combining far-sighted national policies with co-coordinated international action;

If further emphasis is needed, it is provided by the Ramsay Criteria for the recognition of wetlands. From 8 criteria, seven concern biodiversity while four focus on waterfowl and fish. (Box 3)

Box 3: Criteria for Identifying Wetlands of International Importance as adopted by the 4th, 6th, and 7th Meetings of the Conference of the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971) to guide implementation of Article 2.1 on designation of Ramsar sites (http://www.ramsar.org/key_criteria.htm - accessed February 2005).

Group A of the Criteria. Sites containing representative, rare or unique wetland types

Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographical region.

Group B of the Criteria. Sites of international importance for conserving biological diversity

Criteria based on species and ecological communities

Criterion 2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.

Criterion 3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographical region.

Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.

Specific criteria based on water birds

- Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more water birds.
- Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of water bird.

Specific criteria based on fish

- Criterion 7: A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.
- Criterion 8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.

Of course, the hydrological functions of wetlands are given some secondary emphasis. However, apart from stating that wetland resources should be ‘used wisely’, early Convention documents did not stress the importance of wetlands as a human habitat and, apart from the impact on biodiversity, gave little attention to the role of wetlands in watersheds

[37]. Equally, while it is clear that Ramsar includes upland, peatland and alpine wetlands, its major foci remain lowland, estuarine and littoral wetlands [30, 37]. In fact, Ramsar has not yet discovered 'headwaters'. A keyword search for the word 'headwater(s)' finds the word in just 33 (25) instances, 'alpine' discovers 84, upland - 64, mountain – 340. By contrast, the keyword bird(s) produces 1549 (887) records.

However, in recent years, Ramsar meetings have worked hard to build out from of this early, 1970s, mind set. Ramsar's Third Conference of the Contracting Parties (CoP) in 1987 defined the wise use of wetlands as "*their sustainable utilisation for the benefit of mankind"* [33]. Later, it was agreed that Contracting Parties to the Convention should recognize that *"wetlands, through their ecological and hydrological functions ...* (please note the sequence*)... provide invaluable services, products and benefits enjoyed by, and sustaining, human populations"* and that these functions should be sustained...

Later Ramsar meetings have begun to focus greater attention on the problems of headwater wetlands and their inhabitants; the Ramsar CoP7 meeting was entitled: *"People and Wetlands: the Vital Link"* [36]. Most recently, there have been special initiatives on mountains, especially the Andes and Himalaya [37]. In 2004, Ramsar delegates convened to wonder about setting the 'downstream altitudinal limits' for high-altitude wetlands; and the extent to which they should worry about linkages with the downstream parts of the river basins [35]. This meeting on the Himalaya, organised in France, produced three recommendations that have long been part of the central argument of headwater control (cf. [15, 16, 26]. These involved the promotion of community-driven participatory management; the reevaluation of wetland 'ecosystem services as a tool for informing decision-making'; and the re-examination of the 'links between upstream - downstream livelihood support systems' [26, 35].

Nevertheless, Ramsar priorities remain rooted in tradition – first biodiversity, especially birdlife using wetlands, second wetland species, third wetland hydrology and fourth wetland as a human resource. In fact, this is not a wholly negative situation. Stern and Dietz [42] recognise three environmental value systems. 'Egoistic' values predispose people to protect environmental attributes that affect them personally. 'Altruistic' values subsume concern for environment within the welfare of human society. 'Biospheric' grant primacy to all life, including that part which is human. The headwater literature tends to conceive human communities as integral parts of the watershed system and often argues that human welfare is best served by serving the needs of Nature [1]. However, the Ramsar Convention's focus on the properties of the wetlands themselves has not helped the development of wider studies that examine the role of wetlands from the anthropocentric standpoints of integrated watershed management.

5. Headwater Control

The modern concept of ‘Headwater Control’ emerged in the late 1980s, in parallel with the transformation of the former Socialist Countries. It arose from the shared concerns of applied environmental scientists, especially field operatives in forestry, soil and water conservation and water resource management, who work in uplands and on the margins of surface water systems. It contained the search for a more holistic, hands-on and sustainable approach to watershed management.

Like many revolutions before it, the ideology was born from informal coffee shop discussions of the disaffected, who were, in this case, participants at a mountain hydrological meeting. Here, most platform speakers seemed to have lost contact with both the realities of the environment and the needs of its inhabitants and, instead, become obsessed with the fine tuning of some, often alarmingly arbitrary, computer models. The presentations seemed finely tuned to the task of producing the kind of technically elegant academic publications that are considered pleasing by academic peers and funding agency offices. However, when it came to solving problems on the ground, these works seemed remote in every sense.

The ‘Headwater Control’ initiators, however, had aspirations that extended beyond the academy and a wish to engage with the real world of environmental problem solving on the ground. In particular, they were concerned about the way that headwater regions are managed. Often management was effected by outside interests and often by agencies whose interest was also restricted to the exploitation of a single resource. This resulted in blinkered, partial management, often to the disadvantage of the local environment, economy and population. The solution was to promote a more holistic approach based on the integrated locally-empowered, synthesis of lands and livelihoods [2].

In 1989, the first International Conference on Headwater Control, held during the velvet revolution in Prague, brought together several small professional NGOs to discuss the practical problems of headwater regions. Subsequent meetings were organised in Sec, (Czech Republic) 1992, New Delhi and Simla (India) 1995, Merano (Italy) 1998, Liberec (Czech Republic), 1998, Nairobi 2002, Marienbad (Czech Republic) 2003 and

Bergen (Norway) 2005 [13, 14, 15, 16, 17, 18, 22, 24, 25, 26, 27, 40]. The Nairobi Declaration was the main output from the Fifth International Conference on Headwater Control, which was the first to be organised under the wing of the United Nations University [22].

6. Headwater Control Movement

The aim of Headwater Control is to define and implement appropriate self-sustainable management strategies that meet the needs of the headwater habitat, including its human inhabitants, as well as those of habitats and communities downstream. Its works are published in a series of proceedings from the regular meetings of the *International Association for Headwater Control* [14, 17, 22, 24, 26, 40]. Much of this writing is scientific and technical. However, it also demonstrates an evolution in watershed management thinking, especially a shift from the desire to 'control' and towards a desire for self-sustainable 'self-control' of headwater systems.

Headwater Control is constructed on three principles.

♦ 1. Headwater environments are threatened by environmental changes due to human action. So, headwater meetings routinely deal with problems caused by forest decline, land degradation, deteriorating water quality, and the damaging effects of air pollution, agriculture, road construction, tourist developments and mining.

♦ 2. Direct intervention can secure environmental quality. Headwater meetings illustrate many cases where pollution control, forestry, soil conservation, bioengineering and/or community action have improved the quality and vitality of the headwater environment.

♦ 3. Solutions demand the practical application of co-ordinated and integrated environmental management. So, headwater controllers strive towards the holistic integrated treatment of headwater landscapes – in both their biophysical and social components.

Throughout, the aim remains to find an approach that unites the imperatives of environmental conservation, (self-) sustainable development, environmental reconstruction, the empowerment of headwater peoples and the regeneration of livelihoods, through policies and institutions that promote appropriate action.

For the future, it is hoped that more may be done to develop the role that could and should be played by environmental education for sustainable development because, over recent meetings, it has become obvious that improved watershed management, like all environmental management demands a change in social attitudes. This includes a shift in emphasis from granting primacy to short-term economic gains and away from belief in the, still current myth, that it is desirable for technology, routinely, to replace the functions of nature (Berry, 1999). It is hoped that such headwater thinking may influence the agendas of the United Nations Decade of Education for Sustainable Development (2005-2014) [44].

Meanwhile, over the years, headwater meetings have generated a broad consensus on the problems that face these special lands [14]. The common problems include: soil, forest and water resource degradation and pollution by various external agencies and poor management structures. Effective headwater management continues to require better technologies, better policy frameworks, changes in land husbandry patterns and direct engineering intervention. Research needs to be reoriented to focus on the tolerances, exchanges, checks and balances within headwater landscapes and the impact of changes downstream. There is a need for new data, especially from longer-term environmental monitoring and also for new models of headwater management and there is a need for greater sharing and utilisation of existing information.

There is a need to focus on the creation of truly self-sustainable structures, both socioeconomic and environmental. Much watershed management aims to solve problems either by constraining Nature or by taking the functions of Nature into human control. Sometimes this is called ‘sustainable development’. However, in practice, ‘sustainable’ often means no more than capable of being kept going through repair, maintenance and management - a perpetual concern, cost and responsibility for any host community. Headwater control strives for self-sustainability and to create systems that can look after themselves - either because their support is inherent in normal pattern of land-use or because environmental management is returned to the self-sustaining hand of Nature.

Experience regularly demonstrates that headwater problems are caused by insensitive, externally-imposed, policies and inappropriately defined institutions, many established for the exploitation of a particular economic resource, often for the benefit of outsiders. Headwater Control strives against the ideas that watershed management is a process where different technical experts isolate particular problems or resources for attention. A decade ago, Keidel [23] adapted the Indian parable of ‘the 4 blind philosophers who describe an elephant’ by imagining seven ‘visually challenged people’ sent to evaluate a watershed for their agencies. Individually, they decide that this is perfect for Nature conservation, for recreation, for water supply, agriculture, forestry, fishing and mining – and each finds that the land was 'made' for their own favoured use beyond all others.

Institutional constraints are a major obstacle to effective headwater management. The headwater literature argues that there is a need for new management institutions that are flexible, holistic, oriented to integrated environmental stewardship and controlled by empowered local communities [45]. It also recognises that, often, it is the socio-economic conditions of a headwater community (as much as the physical environment) that need treatment. Common problems include shortages of scientific and technical expertise; land-use conflicts that pit local against national priorities, weak local economic systems, alienation and rural depopulation.

7. Headwater Wetlands – Results

Few of the wetlands in the NATO countries remain in their natural condition, many have been drained, forested, converted to arable land or other developments (cf. Haigh, this volume) [39]. In recent decades, wetland have become valued, mainly habitats for many endangered species, but also for their other environmental services. At length, it has become recognised that wetlands have special value and that they are threatened by development and merit some protection. For this to be effective, a first step should be an inventory of their distribution and characteristics. Such a survey has been pioneered by Paracchini and Vogt (this volume). Their survey of 27 European nations achieves the first ever mapping of headwater wetlands at the continental scale. The assessment applied CORINE data to the EU15 Countries (excluding Sweden) plus Poland, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, Bosnia and Herzegovina, Albania, Macedonia, a total of 4,650,000 ha. Here, they find that inland wetlands cover some 36,000 ha, less than 1% of the total surface. For the same area, headwaters amount to 1,000,000 ha, while wetlands in headwaters cover just 10,600 ha, about 1% of the headwater area.

However, despite this small extent, there is general agreement that these lands merit greater attention. The documents of the Ramsar Convention argue that highland and headwater wetlands are not receiving attention at local, national, regional or international levels, adequate enough to defend their conservation and sustainable use for the benefit of their peoples [33, 37: Resolution VIII. 39]. Ramsar reports strongly emphasise the importance of wetlands for the conservation of biodiversity.

This theme was also addressed by this workshop. In Hungary, wetland habitats in mountain and hill regions have not been given due attention (Kertesz et al., this volume). However, they sustain many species, including many rare, endangered and endemic ones. They also play an important part in reducing runoff, improving water quality, and in education and research. Markova et al. (this volume) report from Slovakia, which ratified the Ramsar Convention on 1st January 1993 and supported this in 1994 with its '*Act on Nature and Landscape Conservation (Law 287/1994)',* which promotes the complex protection of nature and landscape. The Slovak Republic has 1379 important wetlands but just 12 of international importance, including 2 that are headwater wetlands (Markova et al., this volume). In Belarus, a network of especially reserved natural territories has been created for the preservation of the unique plant complexes of raised bogs that covers 0.25 10^6 ha and 78% of its oligotrophic massifs (Markova et al., this volume). Data from Slovenia emphasises the small extent of most wetland areas, especially in more southerly latitudes. According to the CORINE Land Cover classification, just 0.2 % of Slovenia is wetlands. Among 3500 recorded wetlands, less than one third cover more that 0.15ha (Markova et al., this volume).

However, the fact remains that wetlands provide a wide range of functions that help maintain the presence of water locally in highlands through groundwater recharge and storage. They may also regulate, significantly, the flow of water in rivers downstream and influence extreme conditions of both high and low flow. Balek (this volume) reports that African headwater wetlands (dambos) play a significant role in the hydrological regime of Central Africa. They act as spongy reservoirs, capable of absorbing water during the rainy season and releasing it slowly during the dry season (Balek, this volume). In this respect, these headwater wetlands may be more important than those further downstream.

Unfortunately, these lands are affected also by land degradation and pressures for land-use conversion, sometimes to a greater degree than those downstream. These pressures include drainage, agriculture, forestry and other development (Haigh, this volume). However, there are also larger external influences such as secular climate change (Hočevar et al., this volume) and regional air pollution (Krecek et al., this volume).

In the Czech Republic, the *Protected Headwater Area of the Jizera Mountains* was proclaimed in 1978 to defend the role of local headwater catchments in water and soil conservation. However, in the 1970-1980s, this land suffered massive degradation due to acid atmospheric deposition and badly advised commercial forestry practices, which included forestation with unsuitable species, clear-cutting, poor harvesting methods, ineffective pest control and unsuccessful reforestation. The network of skid-roads and periodical drainage expanded from 1.3 to 4.7 km/km^2. As a result, soil erosion rates increased from 0.01 to 1.34 mm.a^{-1} and up to 30% of sediments reached local water courses causing widespread deterioration in the water quality of streams and reservoirs. Surface waters became characterised by low pH (4-5), high levels of toxic metals (e.g. Al 1-2 mg/l), extinction of fish populations and drastically reductions in zooplankton, phytoplankton and benthic fauna (Krecek et al., this volume).

Novakova and Krecek (this volume) have studied the erosion rills originated by skidding of timber (from 0.3 to 1.2 mm/year). The critical parameter affecting the recovery of rills is their depth. The increasing depth of rills is related to a drop in both vegetation cover and number of species, and also to a higher proportion of hemicryptophytes and plants forming clusters or bunches. These plants do not have a high potential to cover the soil surface and protect it against erosion, so soil erosion is prolonged.

The species richness in healing rills increases significantly with time. From the point of view of soil protection, shallow rills (depth 0 - 0.25 m) recover more rapidly than deep rills (>0.5 m). Vegetation recovery in shallow rills is quite fast, but in deep rills, spontaneous succession is very slow. So, rills >0.5 m require the stabilisation y check-dams etc.

Thankfully, recent years have seen a reduction in air pollution and consequent environmental recovery in the Jizera headwaters. Mean annual pH has risen (5-6), metal concentrations have decreased (e.g. Al 0.2-0.5 mg/l), sulphate deposition rates have decreased by about 40%, fish species such as brook char, *Salvelinus fontinalis*) have been reintroduced and formerly forested wetlands have been stabilised by grass cover. After the clear-cut of acid-rain damaged spruce plantations, Junco effusi-Calamagrostis villosae has become the new dominant plant community, soil mositure levels have increased and, today, these headwater peat-lands are playing an important role in fixing the Al^{3+} in organic complexes that are not toxic for fish (Krecek et al, this volume).

In fact, peat bogs are net sinks for many environmental chemicals such as CO_2 and N (Haigh, this volume). For example, the accumulation of organic matter in the peat-lands of Poland has been estimated at about 3 million tons (Markova et al., this volume). Carbon sequestration in northern peat lands has been estimated at 0.2-0.5 MgC.ha.a^{-1} [4, 5] and measured as 0.22 and 0.25 MgC.ha.a^{-1} on undisturbed peat at two Scottish sites [19]. The decomposition of carbon from decaying organic matter is severely delayed under the anaerobic conditions of poorly drained or waterlogged peat soils. Most peat bogs are net sinks for CO_2 and many other environmental chemicals.

However, environmental changes including drainage and forestation can affect sequestration, indeed disturbed peat soils tend to become net carbon sources. Drainage of peat reduces the anaerobic zone, so drained and recently forested peat wetlands can exhibit substantial and extended carbon dioxide release (>0.3 MgC.ha.a^{-1}) on afforested peat after 26 years (Haigh, this volume).

In the UK, bogs lose their capacity to sequester carbon in warm years, global warming may raise local temperatures sufficiently by 2021 for most UK peat lands to become net carbon sources [3]. In northern Canada and Eurasia, permafrost covers large areas. Kershaw (Markova et al., this volume) reports permafrost warming by 1ºC during the past thirteen years. Permafrost depths can exceed 12m, so thawing can increase the liquid water storage capacity by 60%. This could result in reduced peak flows following snowmelt and high rainfall events and increased year-round base flows in affected drainage basins.

In the mountainous headwaters of Japan's Lake Biwa catchment, the forestation of degraded lands has reduced annual sediment yields from 5,000 -10,000 $m^3km^2yr^{-1}$ to $10m^3km^2yr^{-1}$. Sediment yields from reforested headwaters have also, with time, decreased from 5.0-10.0 to $0.1m^3km^2yr^{-1}$ (Fukushima, this volume). Of course, because of water loss to evapotranspiration, degraded steepland supplies much more water downstream than forested areas but river water from bare land also contains 100 to 1,000 times more sediment than that from forested areas. Simulations of the hydrograph 100-years after reforestation suggest a regime that is much less peaked and flashy than that from the degraded lands (Fukushima, this volume).

Runoff from peat land is supposed to be dominated by surface and near surface flows causing large flood peaks. Water balance studies of a small blanket peat catchment on Cloosh Forest, County Galway, Ireland, found that the net water receipt was equal to runoff in fully saturated blanket peat (Chandran et al. this volume). However, in Wales, Waunafon's degraded valley fen peat moorland includes organic layers up to 0.5m deep that are unsaturated in summer. So while, overland flow may be affected by rainfall onto saturated ponds, runoff in soil pipes, and through channel incised between the tufts of heath, this degraded peat land has a significant storage capacity in summer and commensurate capacity for seasonal flood attenuation (Haigh and Kilmartin, this volume).

Around 13% of the UK is peat wetland. Since, the perceived value of this land has been low, much has been converted to agriculture and forestry; since 1945, about a fifteenth has been forested (Haigh, this volume). Beheim (this volume) argues that successful afforestation will lead to reduced storm runoff as evapotranspiration increases. In Norway, snowmelt runoff also falls due to decreased snow melting rates and less snow accumulation. Forest dampens snowmelt runoff because snow accumulation may be 30% less in forest stands than clearings. Snowmelt in dense forest stands is about 2 mm/degree day compared to 3 to 6 mm/degree day in clearings because of the increased albedo.

Kubin (this volume) examined the effects of natural regeneration of conifers and clearcutting-followed-by-planting on nitrates in groundwaters, the latter through a 17-year study, at the Pahalouhi experimental site, Kivesvaara, Finland. These treatments both caused a rise in nitrate nitrogen concentrations, but leaching during the first two years from natural regeneration was than that following clear-cutting and planting. From a base of zero, the concentrations of nitrate nitrogen rose to a peak of 500-700 µg/1 after 5-7years. Later, concentrations began to fall again but they remained high 17-years after clear-cutting.

In Norway's Glomma watershed, forest drainage did not cause higher runoff rates and increased flood peaks because only a small portion of the watershed was drained and because forest growth increased after drainage. However, in smaller watersheds with a higher proportion of drained peat lands, the flood peaks would likely increase after drainage (Beheim, this volume). In the UK, perhaps 20% peaty uplands have been drained. Here, the traditional view is that un-drained peat lands adsorb rainwater but are poor aquifers and act mainly as surface flow systems that do little to moderate floods. By contrast, after drainage, peat lands moderate flood flows thanks to increased soil storage although drainage ditches also increase the speed of runoff and encourage erosion (Haigh, this volume). Hence, during small rainfall events on unsaturated mires, most rainfall is stored and runoff is delayed but heavy rainfall on saturated peat can lead to faster runoff (Beheim, this volume).

However, the main hydrological effect of drainage is through changes in the pathways of water movement through the soil and these can lead to either increased or reduced runoff peaks (Beheim, this volume). Where the peat has low hydraulic conductivity, which is often the case with fens, drainage will result in a relatively high ground water table, low water storage capacity and rapid runoff. On mires with a high fibre content, low density and degree of humification, the conductivity and storage capacity can be relatively high and drainage will result in increased water storage and reduced flood peaks (Beheim, this volume). As time passes after drainage, the peat becomes saturated due to compaction by subsidence and increased decomposition, which in turn causes the runoff to increase again. Again, the impacts of ditching depend on the type of mire. Ditching may increase runoff from valley fens supplied by water from fields upslope by causing the runoff to cross the fen faster than it would have done in its natural state.

Peat headwaters produce storm runoff that is acidic but drainage increases the chemical loading of most ions and reduces pH. Burning moderates pH but forestation encourages acidification Overgrazing, trampling and burning also encourage accelerated runoff and erosion. Hill farming fosters pollution through the release of organophosphate sheep dip, fertiliser and pesticides, including the Asulam used to control bracken in the UK (Haigh, this volume). Ultimately, the conversion of wetlands, and their consequent misuse may lead to land degradation and a reduction in their productivity. This reduces their value to the local community while those downstream are affected by poorer quality water supply.

In the developing world also, the management of headwater wetlands is much influenced by human intervention. Wood (this volume) emphasises that the way wetlands are managed is affected by popular perception of their capacity to produce economic benefit. Today, in southwest Ethiopia, wetlands are used by virtually every household and play a critical role in food security. Wetland degradation, however, is linked less to intensity of use than to wider aspects of catchment management.

In Israel, Gophen (this volume) emphasises that effective management depends on successful collaboration between stakeholders. In Israel, the "Hula Project", a constructed wetland ecosystem includes areas of natural and introduced vegetation, agriculture, and the shallow Lake Agmon and a system of drainage channels. This multifunctional wetland has important roles in water supply, agricultural production, ecological conservation and also the tourist industry, which depend upon defining efficient synergies between farming, nature preservation and water quality protection (Gophen, this volume). Management of the water regime is critical because this water must satisfy both local needs for irrigation and the conservation of, the fragile peat soils and also contribute to the national water budget, where there is general concern for water supply and the protection of water quality.

Headwaters and mountains are far from synonymous. Most headwaters are not at high elevations or on steep slopes. Indeed, they may be the dominant features of plains and plateaux. Work by Parachinni et al. [29] showed that, in Europe, headwaters are evenly distributed with respect to altitude. However, many headwater regions are in mountain steeplands. These mountain headwaters are frequently source areas for natural hazards (cf. Hočevar et al., this volume). At the Alpinarium in Galtür, Austrian Alps, environmental education emphasising sustainability and the dualism of headwaters, as a resource and a hazard, is advanced as a topic of the highest public interest and relevance (Hama et al, this volume). Environmental education is seen as a key part of promoting sustainable development in mountain regions (Hama et al. this volume).

Valentinelli (this volume) reports on the Pian di Spagna wetland in the Italian Alps, which was flood prone until 1858 when the Adda River was diverted into Lake Como Lake forming the new separated Mezzola Lake. The area's ecological value was recognized in the framework of the Ramsar Convention, a natural reserve was created in 1996. Despite the area being contaminated by critical concentrations of chromium, little attention has been paid to environmental reconstruction based on wetland rehabilitation and flood prone area recovery. Valentinelli comments that ecological networks, focused on the prevention of natural hazards, require, multisectoral land use planning and better coordination of protection measures.

Landslide activity is a major mode of wetland generation in headwaters. Traykov et al (this volume) studied the ecology of shallow landslide lakes in the Balkan Mountains. The aim was to clarify the role of plankton in the eutrophication of landslide lakes. The study found that re-suspension processes and interactions between the water and sediment, played a key role in the biological and chemical processes of these lakes and their marginal wetlands. In the Italian Alpine region, Marchi et al (this volume) comment on the intense silting of such lakes and the problems this causes for environmental management. Their case study of Alleghe Lake, a landslide-dammed lake dating from 1771, takes into account its role in the local economy and the need to clear away sediment to restore lake-like, rather than wetland like, conditions (Marchi et al, this volume).

While the Alleghe Lake communities try to prevent the generation of wetlands, others are active in their creation. Loza (this volume) describes the positive ecological properties of wetlands created by coal mining in the Ukraine. However, Brydon et al. (this volume), who work in Canada, describe the role of constructed wetlands in urban areas for controlling water detention and water storage during storm events, and water release during dry periods. They argue that such wetlands help reduce peak flow and increase low flow runoff into streams while also retaining and remediating contaminants. Their research on the amelioration of urban stormwater suggests that the effectiveness of metal reduction in water is highly variable and remains a challenge to be resolved by improved wetland design. The importance of such wetlands, however, may increase as urban development encroaches further onto steeper terrain (Brydon et al., this volume).

Achouri (this volume) points out that watershed degradation is a threat to the environment and to the livelihoods of millions of people. Wood (this volume) argues for sustainable development, stressing the need to achieve a balance between environmental and socio-economic needs, while noting that the extreme perspectives of pure conservation and total development are still widely held and these pressures are reflected in many governments' policies. The problem, in many locations, occurs because wetlands, like headwaters in general, fall under the jurisdiction of different agencies with varying, often conflicting perspectives on their best use persists (cf. Vallentinelli, this volume). Achouri (this volume) adds that while much progress has been made in watershed management in recent decades, especially the new approaches that promote participatory integrated watershed management [45], no clear picture has been drawn of what is really working and how to improve future watershed management programmes. In-depth analysis of the state of the art and the identification of gaps is a prerequisite to further development (Achouri, this volume). It is hoped that this workshop has contributed to this goal.

8. Conclusions

The formal conclusions of the *"Environmental Role of Headwater Wetlands"* workshop were generated during the meeting's plenary session, in which all delegates sought to contribute their findings to a list created on a flipchart. Although many ideas were listed, and many subsequently deleted, during discussion, the following was obtained.

It was accepted that, in general, traditional areas of headwater wetland have been undervalued by national and regional administrations. In addition, the needs and potentials of these areas have not been served well by activities under the Ramsar Convention on Wetlands, which tends to treat wetlands as isolated features rather than in their wider landscape context, which tends to emphasise ecological characteristics more than hydrological, and which tends to undervalue the productive potential of wetlands for local people. By contrast, the effective management of headwater wetlands demands their full integration in environmental management plans. Towards this end, a new and comprehensive inventory of headwater watersheds is urgently required.

The aim of management should be to maximise the benefits of these wetlands to their stakeholders. However, better environmental understanding is required to minimise the potential negative impacts of environmental processes such as emissions of greenhouse gases and hydrological changes which affect flooding, water chemistry, and sediment release. There remains a need to assess the role of wetlands in current and future land use systems, especially farming, forestry, grazing, water resource management, tourism, and nature conservation. Effective management of headwater wetlands in the frame of integrated watershed planning also demands some assessment of the role of key components such as riparian buffer zones, runoff genesis, and water supply as well as a better system for community education and more effective participatory management processes. Current research evidence is ambiguous but the present presumption favours some investment in the conservation of some wetlands and in the restoration of the most degraded areas, especially those used for tourism or nature preservation.

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ERRATUM

Erratum to: Environmental Role of Wetlands in Headwaters

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The chapter entitled "The Effect of Peat Land Drainage and Afforestation on Runoff Dynamics: Consequences on Floods in the Glomma River" (pp. 59–75) published in the first printing of this book under the authorship of E. Beheim has been retracted after it was established that the contents were plagiarized from an earlier publication authored by Bjørn Kløve of Bioforsk at the University for Life Sciences, Ås, Norway.

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