FORSTLICHE SCHRIFTENREIHE
UNIVERSITÄT FÜR BODENKULTUR, WIEN

Band 18

Robert Jandl, Herbert Hager, Willi Loiskandl,
Martin Gerzabek, Harald Mauser, Otto Moog,
and Hanno Richter (Editors)

WATER AND SOCIETY

Needs, challenges, and restrictions

Proceedings, International Conference, held at
University of Natural Resources and Applied Life Sciences,
Vienna; November 19-21, 2003

ÖSTERR. GES. F. WALDÖKOSYSTEMFORSCHUNG
UND EXPERIMENTELLE BAUMFORSCHUNG
UNIVERSITÄT FÜR BODENKULTUR
DEZEMBER 2004

TABLE OF CONTENTS

INTRODUCTION

"Water and Society – Needs, challenges, and restrictions" An International Conference held at Universität für Bodenkultur Wien November 19 to 21 2003 and organized by Herbert Hager, Harald Mauser, Martin Gerzabek, Otto Moog, Robert Jandl. Willi Loiskandl and Hanno Richter.

Mankind utilizes freshwater for many purposes which range from drinking and hygenic use, irrigation of crops, industrial use, the generation of energy, to transportation of bulk goods and recreation, and even as medium for waste disposal. Vast quantities of water are extracted from rivers, lakes, underground aquifers, and wetlands to supply the society's requirements. A wide range of ecological and human crises results from shortage or inadequate access to, and the inappropriate management of freshwater resources. Despite of freshwater extraction and consumption of water resources the health, function and integrity of aquatic ecosystems needs to be sustained, as it is spelled out in many national and international laws and legal frameworks or directives. Ecosystem benefits are costly and often impossible to replace, when aquatic systems are degraded. Water is also of immense cultural relevance. It many religions and beliefs around the world it represents rebirth, it cleans the body, and by extension purifies it, and these two main qualities confer a highly symbolic status to water. Water is therefore also a spiritual element in many ceremonies and religious rites.

Austria is a privileged country with respect to the abundance of freshwater resources and their renewal. In many regions of the world, the amount and quality of water availabe is limited. The gap between supply and demand will widen in the future due to the increasing consumption and climate change. – Besides the beneficial qualities of water there are many dangers inherent. Natural disasters caused by torrential rainfalls, flooding, and avalanches are all too familiar headlines which confront us frequently form the media. Often these events are accompanied by immense economic losses, destruction of infrastructure, and always by great suffering and loss of human lives. The importance of water is apparent from the numerous governmental agencies that take care of water in the environment or the landscape or share responsibilities for various aspects of the water cycle. Water is ubiquitous on the agenda for research and education. It is an element in the curricula of all biological and numerous technical sciences. We seek to understand water from many perspectives, ranging from its molecular structure, its physical properties, to its dynamics in porous media or in open channels, furtheron to its ecological significance, and to the water relations of plants. Water is an important element in the landscape. Risk management is the major goal of torrent and flood research. All these fields were represented by the organizing institutions of this conference. The UNESCO has devoted the year 2003 to the highly complex set of themes and named it the Year of the Fresh Water.

This volume of the Forstliche Schriftenreihe der Universität für Bodenkultur assembles 12 papers that represent the wide range of the topics of the above quoted international conference 'Water and Society – Needs, challenges, and restrictions'.

We thank the authors for their contributions and the reviewers for their efforts.

On behalf of the organizing committee

Robert Jandl, Willi Loiskandl and Herbert Hager (Editor of Forstliche Schriftenreihe, Wien)

EXPERIMENTAL DESIGN FRAMEWORK TO RESTORE ECOLOGICAL SERVICES AND ECONOMIC RESILIENCE IN THE TISZA RIVER BASIN

EXPERIMENTELLER RAHMENPLAN ZUR RESTAURATION ÖKOLOGISCHER LEISTUNGEN UND DES ÖKONOMISCHEN GLEICHGEWICHTS IM EINZUGSGEBIET DER THEISS

Jan Sendzimir, Peter Balogh, Anna Vári

Institute f Applied System Analysis (IIASA), Laxenburg, Austria

ABSTRACT

The sustainability crisis in the TRB has developed slowly and incrementally over the past 130 years since implementation of the original Vásárhelyi plan. The high visibility of floods caused most resources to be funneled into a massive flood defense system that repeatedly failed to match the rising intensity and frequencies of floods. The Hungarian public view, blinded by flood and toxic spill catastrophes, missed the slow and subtle changes to natural, social and human capital precipitated by the reshaping of the TRB landscape and its agriculture. While conversion of the TRB from a polyculture to a monoculture produced a great deal of financial capital for an aristocratic minority, the gradual drain of alternatives forms of capital left the region less and less resilient in the face of ecological (floods), economic (globalization) and political (war) shocks. Domination by central authorities over the past 50 years reduced local civic capacity to levels of passivity that make most communities incapable of innovating to find sustainability solutions, and this trend is reinforced by on-going paternalistic attitudes in the Hungarian national government. Efforts to achieve sustainability should aid stakeholders at local, regional and national levels to see how the situation developed and experiment with policies to rebuild the region's heritage. Understanding requires new ideas on value (alternative forms of capital) and change (resilience theory) to be tested in local and regional experiments that identify how to improve these ideas as well as practices to implement them. Efforts to link understanding with innovative practices require citizen-science dialogues, such as Adaptive Management (AM), to allow cooperation between stakeholders and actors in all phases of research, management monitoring, and formulation of policy. We describe how the adaptive management process is designed to address uncertainty and give examples of AM applications in Florida and Poland. We conclude with a proposal as to how AM could be applied to help scientists and stakeholders work together to experimentally determine what kinds of agriculture and fisheries methods could take advantage of reflooding of the Tisza river floodplain.

KEYWORDS: Adaptive Management, Floodplains, Flooding, Polyculture, River Renaturalization

ZUSAMMENFASSUNG

Die Nachhaltigkeitskrise im Einzugsgebiet der Teise hat sich langsam und schrittweise im Laufe der vergangenen 130 Jahre seit der Implementierung des ursprünglichen Vásárhelyi Plans entwickelt. Auf Grund der unübersehbaren Überschwemmungen wurde ein Großteil der finanziellen Ressourcen in massive Hochwasserschutzanlagen geleitet, die jedoch auf Grund der steigenden Intensität und Frequenz der Überschwemmung immer wieder versagten. Die Ungarische Öffentlichkeit, verblendet durch die Überschwemmungen und katastrophalen Wasservergiftungen durch ausgelaufene Chemikalien, nahm die langsamen und subtile Veränderung des natürlichen, sozialen und humanen Kapitals nicht war, die durch die Umgestaltung der Landschaft und der Landwirtschaft verursacht wurde. Die Umwandlung des Einzugsgebiets der Teise von einer Poly- zu einer Monokultur erhöhte zwar das finanzielle Kapital einer aristokratischen Minderheit, verringerte aber allmählich die anderen Arten von Kapital, wodurch die Region immer weniger widerstandsfähig gegen ökologische (Überschwemmungen), ökonomische (Globalisation) und politische (Krieg) Schocks wurde. Die Vorherrschaft der Zentralautorität während der vergangenen 50 Jahre reduzierte die örtlichen bürgerlichen Fähigkeiten bis zur Passivität, wodurch die meisten Kommunen unfähig wurden nachhaltige Lösungen zu finden. Dieser Trend wird momentan durch die paternalistische Einstellung der Ungarischen Regierung verstärkt. Bemühungen zur Erreichung von nachhaltigen Lösungen sollten locale, regionale und nationale Stakeholder helfen die historische Entwicklung zu verstehen und sie zu Experimenten ermutigen um das regionale Erbe wieder aufzubauen. Dieses Verstehen braucht neue Ideen für Werte (alternative Formen von Kapital) und Wandel (Theorie der Belastbarkeit). In örtlichen und regionalen Experimenten sind diese Ideen und deren Implementierung zu testen und zu verbessern. Um das Verstehen des Systems mit innovativen Implementierungen zu verbinden ist ein Dialog wie der des Adaptive Management (AM) zwischen Bürgern und Wissenschaftlern nötig. Dadurch wird eine Kooperation zwischen Stakeholdern und Akteuren in allen Phasen der Morschung, des Management Monitoring und der Formulierung von Strategien möglich. Wir beschreiben wie der AM Prozess konzipiert wird um Ungewissheiten anzusprechen und geben Beispiele von AM Anwendungen in Florida und Polen. Wir schließen mit einem Vorschlag wie AM Wissenschaftlern und Stakeholdern helfen kann zusammen zu arbeiten, um experimentell die Art von Landwirtschaft- und Fischereimethoden zu bestimmen, die sich das wiederholte überschwemmen der Tisza Flußauen zu Nutze machen.

SCHLAGWÖRTER: Adaptive Management, Wassereinzugsgebiet, Überschwemmung, Polykultur, Flußrenaturalisation

INTRODUCTION

The Tisza river flows from the Trans-Carpathian region of the Ukraine, and, fed by numerous tributaries from Romania and Slovakia, cuts across the Great Hungarian Plain (*Alföld*), the largest sedimentary basin in Europe (Juhász 1987, Sümegi 1999). While the length and breadth of the Tisza River Basin (TRB) are not imposing in size (Figure 1), the vast differential between them and the far larger four nation area (more than 150 000 square kilometers in parts of Ukraine, Romania, Slovakia and Hungary) it drains give the Tisza some of the most dramatic flow fluctuations in Europe (Kovács 2003). Loosely hemmed in by the bowl shape of the *Alföld*, these fluctuations spread as sharp crests of flood waves over vast areas of floodplain, suspended there for considerable periods by thick, impermeable sediments. Pre-industrial societies managed to develop cultures that could utilize and thrive on massive, periodic flooding, building fisheries and fruit enterprises that made them one of the richest regions of Hungary before 1850 (Andrásfalvy 1973, Molnár 2003, Paget 1855, Tóth 2002). How could such a wealthy region collapse to its present economic and social poverty, threatened increasingly by the very floods on which it used to thrive?

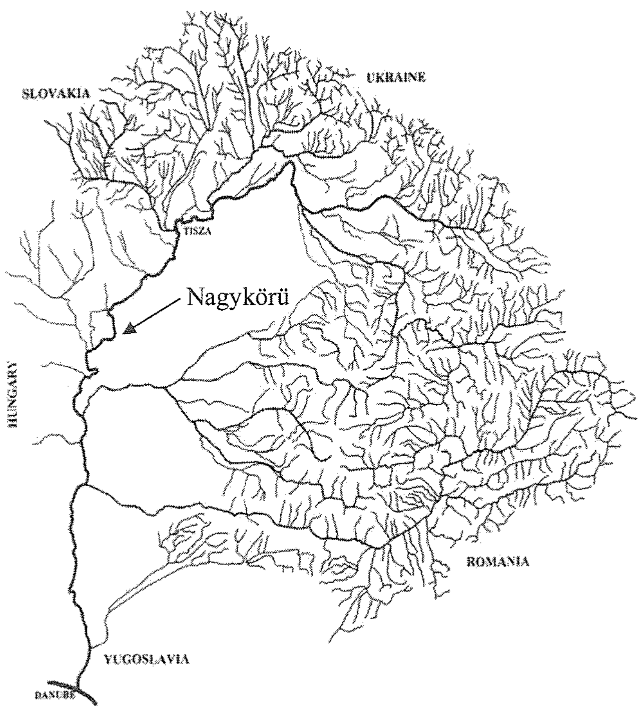


Figure 1: The Tisza river basin with all its tributaries i n the Carpathian mountain range across portions of five different national territories (Romania, Ukraine, Slovakia, Federation of Serbia and Montenegro, and Hungary).

Abb. 1: Das Tisza Einzugsgebiet mit allen seinen Nebenflüssen in den Karpaten, verteilt auf fünf nationale Territorien (Rumänien, Ukraine, Slovakai, Federation von Serbien und Nontenegro und Ungarn).

This paper examines some of the sources of uncertainty from both human and environmental sources that have combined to produce such surprising regional collapses. It then considers examples of participatory science-policy dialogues, such as Adaptive Management (AM), that have proven useful in addressing uncertainty in river basins, and suggests how an AM process could guide long-term series of experiments to uncover key functional relationships and re-establish the resilience of TRB ecosystems and society.

Challenge of Rising Uncertainty

Much of human history records our vulnerability to catastrophic surprises: storms, earthquakes, plagues, droughts, floods and other forms of Natural variability. For example, Europe is less than one millennium removed from times when unpredictable weather precipitated famines every decade or so (Danny and Danziger 2000), and most societies around the world have much fresher memories of these and other calamities. While the ebb and flow of human events might appear chaotic and capricious, we instinctively look outward from society to the environment as a powerful source of uncertainty and change.

Confidence in human capacity to manage Nature surged with the dramatic scientific and engineering advances that drove the Industrial Revolution like reciprocating strokes of a combustion engine (Davies 1996), increasing society's throughput of energy and materials by several orders of magnitude (Odum 1996). That confidence faded with a series of surprising, catastrophic collapses of regional fisheries, agriculture and forestry in the 20th Century (Gunderson et al. 1995, Holling 1986, Walters 1986). The "stubborn" refusal of many such crises to respond to any remedy has earned them the reputation as "wicked" problems (Rittel and Webber 1973). In many cases, policies that initially "cured" problems have suddenly foundered on "policy resistance", the counter-intuitive, often delayed, emergence of new challenges that would reverse initial success (Sterman 2002).

Overview of Uncertainty

The degree and quality of uncertainty inherent in the dynamics of ecological, social and economic change can be classified as statistical uncertainty, model uncertainty, or fundamental uncertainty (Hilborn 1987). Lay discourse about change may acknowledge the shallowest level of uncertainty, statistical uncertainty, wherein one may not know the condition of a variable at any one point, but the overall chances of its occurrence (probability distribution) are known. An example of this might be the chances of being struck by lightning. More profound kinds of uncertainty are currently encountered at the frontiers of science and practice. For example, the depth of surprises occurring in natural and human systems are forcing us to re-examine our most basic ideas about how variables are connected in a model (model uncertainty) or whether we can conceive of any model at all that applies (fundamental uncertainty) (Peterson et al. 1997). In the case of model uncertainty one still can predict outcomes but have no idea of their likelihood. For instance, evidence from periodic drops in Europe's temperatures are best explained at present by the switching off of a deep ocean current, the Atlantic Conveyor, yet we have little idea what processes combine to toggle these systems on and off and less of an idea of their likelihood (Broecker 1996, IPCC 2002). Fundamental uncertainty applies to situations so novel that no current model applies. The discovery of the atmospheric ozone hole exemplified such profound novelty; we couldn't even conceive of a cast of characters let alone a set of relationships between them. One begins to appreciate the complexity of socio-ecological systems when one realizes that, as our Earth is increasingly connected by ecological and human processes, all three levels of uncertainty can apply at any one place. Uncertainty, therefore, arises from sources both external and internal to society. We consider two of the most prominent sources of uncertainty currently confronting river basins: climate (external) and our history of river basin engineering (internal).

Uncertainty from Nature

Climate change (CC) is anticipated to increase uncertainty in river management through short-term *direct effects* on temperature and precipitation that may generate medium- to long-term *indirect effects* on the rates and functioning of ecosystem processes and the interactions between them (IPCC 2001, Walther *et al.* 2002, Parmesan and Yohe 2003, Sendzimir et al. in review). CC impacts can complicate flood management by increasing the variability of river inputs from meltwater, groundwater and precipitation. Rising temperatures and shorter winters should diminish both ice and snow volumes thereby decreasing meltwater contributions and increasing the dominance of rainwater inputs to river flow. Over the past 50 years rising atmospheric temperatures have already decreased alpine glacier ice volumes by 50 percent and should completely melt all glaciers feeding the Rhine river by 2050 (souce:*www.waterandclimate.org*) decreasing steady melt water inputs by 15 percent in summer. CC impacts are expected to driven increases in rainwater fluctuations, such as a 20 percent increase in winter precipitation.

Rising temperatures can drive higher throughput of the hydrological cycle with higher evapotranspiration and precipitation rates (IPCC 2001). Higher precipitation rates probably will lead to increased spatial heterogeneity of precipitation, concentrating rainfall into tighter patterns of more intense rain and thereby increasing the likelihood of flooding. Such intensification of the volume and spatial pattern of rainfall is likely to be amplified by human conversion of floodplain land cover from wetlands to agriculture or habitation. This lowers contributions of wetland functions that buffer fluctuations in gases, particulates, nutrients, toxics, water, temperature, and kinetic energy (e.g., wave and wind). For example, wetland productivity contributes to carbon sequestration and evapotranspiration fluxes that moderate air and water temperature variability. As a result, cooler micro-climates over river valleys and marsh plains sustain higher rates of smaller, local rainfall events, thus buffering the basin from more intense rain upstream that generates more extreme flood events (Pokorny et al. 1998, Ripl 1995). The combined decline of steady base inflows and increase in rain driven input variability should increase flood volumes and peak levels substantially. Along the Rhine river, flood peaks should rise 20 percent higher than previously experienced (souce:http://*www.waterandclimate.org*)).

Uncertainty from Human Intervention

The sources of surprise and uncertainty in the TRB emerge not only from the complexity of Nature but also from the ways that human intervention has lowered the basin's resilience to change. We consider here the ways that the basin's structure and function have been altered through shifts in land use and basin morphometry by hydro-engineering.

Hydro-Engineering the Tisza river basin

Fueled by coal the Industrial Revolution realized the promise and power of the ideas of the Enlightenment on a grand scale and began to shake and reconfigure commerce and society in Europe. As Davies (1998) notes: "There is a dynamism about nineteenth-century Europe that far exceeds anything previously known. Europe vibrated with power as never before: with technical power, economic power, cultural power, intercontinental power." A rising tide of energy, raw materials and people converged on growing urban agglomerations that became regional manufacturing centers for new products and economic opportunity, which in turn drew yet more people and resources from the countryside. Nations grew following the new, "modern" industrial model, swelling every index of growth, including urban populations and the demand for food. This demand was seen as a new opportunity by the major landholders on the TRB. The Hapsburg nobility, including the Emperor, as well as Hungarian aristocrats and nobility to some extent, began to convert the agricultural land of the floodplain from a diverse polyculture of fruits, nuts and maize to larger fields with monocultures of wheat (Kovács 2003). There was far more profit in providing a durable grain for the main staple of urban populations, bread, than in handling the enormous variety of perishable fruits, which were far more daunting items to store and ship. Within a few decades Hungary would become the first wheat-exporting nation in

Europe, earning large profits in the short run but at a far higher price in the long run than originally imagined.

Agricultural transformation immediately raised two challenges. First, no variety of wheat known then could withstand flooding or even high groundwater levels for any length of time, so the Tisza had to be tamed to keep its surges off the floodplain. Second, the twisting meanders of the Tisza across the Great Plain had to be straightened to shorten shipping distances and make export profitable. Changing the shape and content of the fields lead to the Herculean task of reshaping the entire floodplain and the river channel itself. Such radical surgery on the landscape was an affront to tradition and sparked great controversy (see Vay Alajos (1885)), but eventually the Vásárhelyi Plan was pushed through in 1870 and the wood and coal-fired power of the 19th century began to sculpt the Tisza River valley with the clean and smooth lines of an engineer's rule (Figure 2).

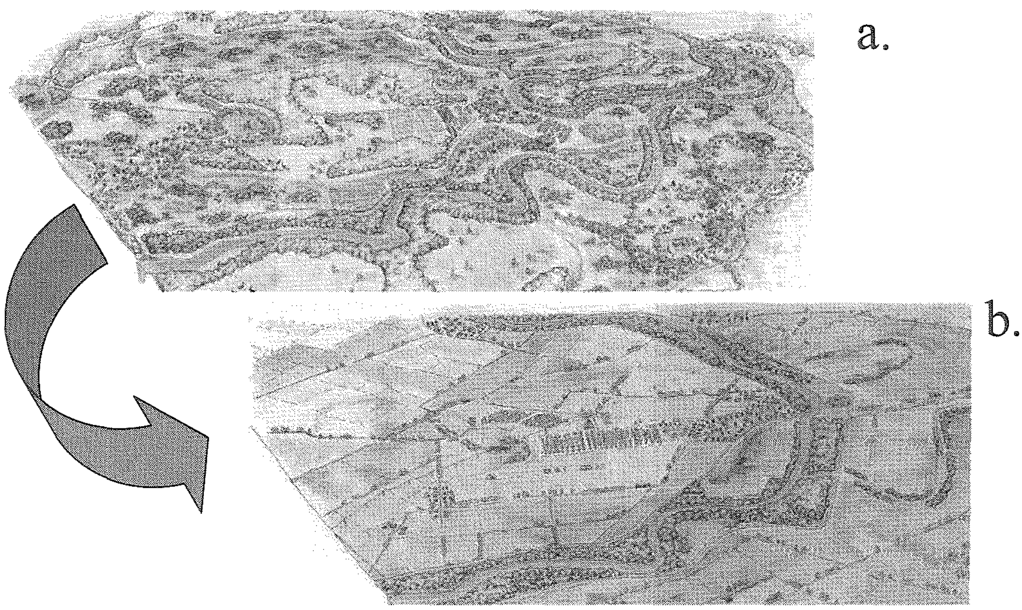


Figure 2: Artists interpretation of different landscape mosaic patterns in the Tisza river floodplain both pre-(a) and post-(b) execution of the original Vasarhelyi river engineering plan in 1871 (Haraszthy, 2002)

Abb. 2: Künstlerische Interpretation verschiedener Landschaftsmosaikmuster im Tisza Einzugsgebiet vor (a) und nach (b) der Implementierung des ursprünglichen Vasarhelyi Flussbegradigungsplan von 1871 (Haraszthy, 2002).

To grow, protect and export wheat the Tisza floodplain was modified for flood defense, and the river was straightened and deepened. Wheat export became possible when the Tisza's flow was concentrated in a single, deeper channel that cut a smoothed arc through the maze of twists and turns of a braided river's floodplain). Overall the Tisza's length was shortened by more than 400 km (Botári and Károlyi 1971). In addition, the original Vásárhelyi Plan began a process that over a century eventually protected 97 percent of the basin at risk from flooding with over 4500 km of primary and secondary dikes along the Tisza and its tributaries (Váradi 2001). This also consisted of embankments around some 840 smaller settlements and circular levees around 48 cities and large villages (Jolánkai 2002, Siposs and Kis 2002). In addition some 40,000 km of canals were added to decrease the groundwater levels and hasten drainage of wheat fields (Szlávik et al 2000). Overall, the dike defense system lowered the floodplain area by more than an order of magnitude, from 38 500 km2 to 1800 km2 (Hamar et al. 1999, Horváth et al 2001
Simply mentioning that a major Tisza flood could inundate 17 percent of Hungary (Ministry of Transportation and Water Management, 2001) made the threat so palpable that it locked most funding into dike defense. Water authorities are driven by enormous political pressure in the event of any loss of life or injury following dike failure in a flood (Linerooth-Bayer and Vari 2003). However, the prodigious engineering of the dike defense system failed repeatedly under the mounting pressure of floods with higher crests and volumes. More and larger floods created a race to raise and reinforce the dikes higher than the next major flood, but the history of dike failures shows how re-engineering the defense system never could catch up. For example, before the 2001 flood, of the 627 km of dikes along the Upper Tisza River in Hungary, 260 km of that length did not meet the government standard, which is 1 meter higher than the maximum flood height of record (Horváth et al 2001). This dike system failed in the 2001 flood, and the total destruction of 1000 homes in an election year provoked a massive show of government support that built new homes and re-engineered the dikes yet again.

Rising flood statistics

In addition to the renowned riverine floods, drastic high water also occurs due to flash floods in hilly areas and welling up of groundwater in low-lying areas, particularly the adjacent floodplain (Pecher et al. 1999). However, swift and devastating riverine floods are the dominant water impact in the Tisza region. Within 24 to 48 hours of major rain events in the surrounding arc of the Carpathian Mountains, the Tisza can surge up to 12 meters above normal levels as rising tributaries swell its volume 100 fold. The fact that such volumes (4000 cubic meters a second) approach half that of the far larger Danube river at flood stage gives some continental measure of the significance of these events. The Tisza may be moderate in dimension, but the forces moving through it are considerable.

The TRB has known large floods for more than a millennium of recorded history and undoubtedly over the eons of geological time since the rise of the Carpathian range. Such extreme floods are currently estimated to occur on average every 10-12 years in the Tisza River Basin (Wu 2000), but the last century has seen rising trends in all facets of flooding: flood crest or peak height, flood volume, and flooding frequency. Floods have increased in peak height by an average of 0.35 to 0.73 centimeters per year in the past fifty years (Horváth et al. 2001). Since the average minimal flow has declined, the difference between flood and drought extremes is increasing. The interval between extreme floods has declined sharply from once every 18 years (1877 – 1933) to once every 3 to 4 years (1934 – 1964) to almost every other year over the last decade. An engineering race to raise the dikes started after each flood, as each subsequent flood exceeded the previous one in height (Fetivizig, 2000)

Practically in step with mounting flood statistics, regional development has also climbed since the mid-nineteenth century, and the clash between these two rising trends has created ever larger losses. The infrastructure of towns and row crop farms burgeoned and spread into the flood danger zone, the TRB floodplain, reassured by the apparent security of a dike and canal flood defense system. The security promised by hydro engineering might hold for a decade or two, but ever-larger floods breached these defenses, devastating homes, roads and crop fields. Damage to built capital and commerce from one major flood event could reach as high as approximately 25 percent of the riverine basin GDP or 7-9 percent of national GDP (Halcrow Group 1999). The most vulnerable groups, such as low revenue farmers, are often hit hardest, depleting their scarce reserves and pushing them to the brink of bankruptcy (Linnerooth-Bayer and Vari 2003). The inadequacy of a century of improving and reinforcing the dike defense system became painfully apparent when the 2001 flood broke through the dikes along the Upper Tisza near Vásárosnamény, completely destroying 1000 homes, damaging 2000 others and forcing the evacuation of 17 000 people (Linnerooth-Bayer and Vári 2003). The force of major floods perennially rises to surpass expensive efforts to engineer, reinforce and defend the dike system. Without a very quick, competent and heroic capability to react to floods in crisis, the failures of hydro-engineering would be even more apparent (Linnerooth-Bayer and Vári 2003).

Summary of Challenges along the Tisza

The TRB faces a complex of related problems that so far have proven too entangled to understand or fix. The subset of inter-linked challenges underlying such "wicked" problems includes ecology (loss of biodiversity, habitat, rising intensity and frequency of floods), economy (farms and related businesses disappearing, loss of fishery, fruit, nut and timber industry) and society (disappearance of schools, communities, children uninterested in history and culture). These problems have been compounded by a series of profound interventions to re-engineer the river basin's morphometry and to completely replace local agricultural methods with dryland wheat production. In ways paradoxical to the modern sense of progress, increasing investments in technology have increased, rather than diminished, the uncertainty facing inhabitants of the TRB. Periodic disasters increase in intensity while the ecological, economic and social bases of resilience erode slowly. Clearly, future actions must be rely on understanding with a wider disciplinary foundations than the narrow engineering and economic concepts applied so far.

ADAPTIVE MANAGEMENT: A LEARNING PROCESS TO ADDRESS UNCERTAINTY

Uncertainty challenges more than our need to understand, because the responsibility to manage systems of humans and nature creates a tension between two needs: for useful simplifications to communicate and probe with (theory) and for effective action (practice). This tension increases as Nature's uncertainty is compounded by society's attempts to learn and manage. Both natural and human systems constantly change and evolve, sometimes in synchrony and sometimes not. If our appreciation of uncertainty forces us to admit that there are no "truths" which persist, and that no person or group is the guardian of such truths, then we can recognize the importance of discussion between a variety of competing ideas. In other words, coping with novelty and surprise requires the sustained capacity to learn and to flexibly manage. For thirty years a decision making process has been evolving to address the twin challenges of learning and management. This process, Adaptive Environmental Assessment and Management (AEAM), also known as Adaptive Management (AM), has been refined in a series of on-the-ground applications in problems of forestry, fisheries, national parks, and river systems (Holling 1978, Walters 1986, Gunderson et al 1995, Gunderson and Holling 2002).

The driving assumption underlying AM is that uncertainty is inevitable, because the behavior of complex systems is only partly knowable. Therefore, as ecosystems and societies evolve, so humans must adapt and conform as systems change. However, change challenges us to respond at a number of levels that include *both* understanding and management. Historically, understanding, when developed in isolation from the discipline of managing a changing system, has often proven shallow and of limited use. Therefore, AM is not about learning before one can manage; rather it is learning while one manages (Gunderson et al. 1995).

Structured learning in an iterative cycle (Figure 3) is the way the AM process winnows uncertainty. Surprise is never eliminated, but we may reduce the consequences of the way our understanding lags behind evolving systems by embracing uncertainty. This "embrace" means moving the emphasis from certainty and control to deepening understanding and adaptively responding to system changes. Adaptive responses and management actions must balance two sets of objectives: social objectives, such as protecting people and resources, and learning objectives. Learning must continue as policies are modified to adapt to surprises. And therefore, a second function of management is to probe the system, perturbing it slightly to provoke some minimal, safe response that gives an indication of the working and true structure of the system and where it is headed(Walters, 1986).

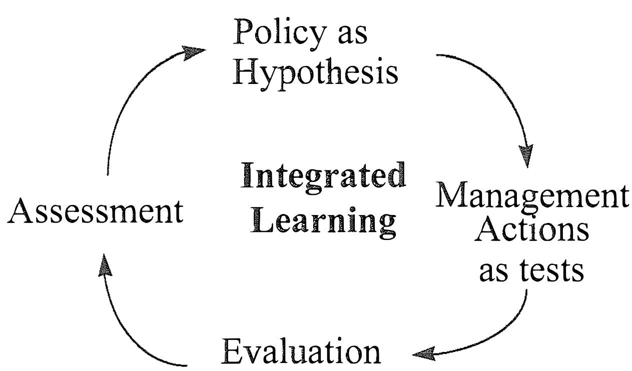


Figure 3: Key ingredients contributing to structured learning in the AM process.
Abb. 3: Illustration – Notwendige Schritte die zum strukturierten Lernen in einem AM Prozess beitragen.

Principles of Adaptive Management

Assessing the Known and the Uncertain

The assessment phase simultaneously engages two apparent opposites, integrated understanding and uncertainty, and counter-poses them in ways that are revealing to both. Rather than dodging uncertainty with simplifying assumptions or rationalizations, the AM process focuses on uncertainty from the very beginning, utilizing disagreements (as well as agreements) to reveal and highlight gaps in understanding and other sources of uncertainty. The assessment process identifies new bases for sharing understanding when gaps or uncertainties are recognized as common to all the different disciplines, sectors, occupations, trainings and experiences represented in the discussion (Folke et al. 2002).

The common gaps and links in understanding can bridge the participants' various backgrounds and establish a foundation of trust that may eventually unlock information and experiences that were previously unshared. Building such trust is one way in which the AM process addresses the refusal to share information, a frequent source of gridlock in environmental decision processes. Another way is to select representatives of various backgrounds based on competence, respect within their group and the willingness to cooperate. Participants are given to understand, that a great potential for communication can emerge if only each person "leaves his/her gun at the door", be that gun an opinion, a philosophy or a mandate from one's organization.

The assessment phase aims to initiate and foster discussion by using an informal workshop setting and computer models. Care is taken to introduce and use computer models simply as translators and integrators of people's understanding, not as technically superior vehicles of "truth." If dialogue begins where there was none before, then the computer model has succeeded. If people begin to seriously reassess their assumptions because model output based on their ideas seems questionable, then important and novel insights are possible. The goal of the assessment phase is to integrate understanding and ponder uncertainties to the point that they can be clearly stated as hypotheses about how the system works and what effects interventions (management or uncontrolled human actions) might produce. Complexity in adaptive systems is partly the result of the diversity of causes, and the alternative explanations that address these causes can become the basis for policy in the next phase.

Policies a s Hypotheses

Policies are the governing plan, the question set based on experience that sets the stage of further action. Policies range from the formal (government acts, laws, administrative code, legal contracts) to the informal (understandings and shared views among groups). Instead of pursuing the 'correct' policy as a solution to problems, AM differs from traditional engines of policy by looking for policy that addresses other social objectives as well as the need to learn in the face of uncertainty (Gunderson 1998). In this light, policies are not magic bullets that address the right mix of objectives to solve a problem, rather they are astute hypotheses about how the world works or "Questions masquerading as answers" in the words of Steve Light. AM embraces uncertainty by trying to find the best questions, and thereby tries to dodge the trap of assuming certainty by rallying around 'solutions.'

Management Actions as Tests

Many environmental problems stem from administrative pathologies that narrow policy to achieve efficiency at the expense of awareness about where the system is going. For example, if initial policies achieve high production, one could bank on maximizing the profit of such success by cutting research costs, but only if one was sure of where the system is going. The AM process strives to avoid this pathology by broadening implementation to mean the testing and evaluating of hypotheses (policies). This prevents the intent of policy from being changed during implementation, and shifts the search for efficiency from cost reduction to checking whether management actions were executed as anticipated (Gunderson, 1998). This gives implementation a disciplinary rigor of consistency in execution, because otherwise the test of the policy becomes meaningless, and one has loses the power to gain new information about the system.

Integrative Learning

Amassing information does little to help anticipate surprise and uncertainty. Projections based on previous system behaviors have limited utility in the face of true novelty. Integration of the information gained in policy probes has little to do with data quantity and everything to do with quality. To what extent have we winnowed uncertainty and closed the gap on these elusive and dynamic systems? An iterative learning cycle enhances understanding by integrating learning at several levels. First, it integrates across multiple disciplines and backgrounds. Second, it integrates through application and practice when the focus group, and the community at large, learns by doing. In this way understanding deepens by probing the workings of ecosystems and society and by thoughtful sharing of new ideas and previous experiences. Such inquiry is structured by expert facilitation of discussion, summing up new insights and consolidating gains before reformulating the questions at hand. Finally, this understanding often builds from ground made more fertile by complete re-inspection of assumptions and conceptual frameworks (Gunderson et al. 1995).

Summary of the AM Approach

Adaptive management is not unique. It is similar to many approaches to understand and manage uncertainty in ecosystems and society (see Checkland 1981, Toth 1988, Senge 1990, Slocum et al. 1995, Pretty et al. 1996, Checkland and Scholes 1999, Kay et al. 1999, van der Heijden 1996, van de Kerkhof 2001, Bousquet et al. 2002, Craig et al. 2002). AM reflects the theoretical and methodological training in ecology and modelling that the professionals used as they developed AM as a framework to deal with regional environmental crises. It represents ecologists' attempts to communicate and work with a variety of disciplines as well as the governance and business sectors of society. It continues to evolve and mature as theory and methods of economics and the social science are incorporated in its application. For example, the study of institutions has gained equal status with natural sciences and economics in the articulation and bounding of the question at hand and in formulating hypotheses and policies (see Ostrom 1999).. AM has not always succeeded. It has been stymied by failure to reach a conclusion or to produce meaningful and concrete results because participants can indulge in endless discussion and modelling if they are not vigilant or are incompetently guided by facilitators. AM has also been criticized as "too theoretical" and therefore impractical to act as a framework for people without advanced education or sophisticated means of discussing complexity. This latter point may depend more on the skill and patience with which AM is applied than with an inherent failure in its design. However, AM still represents a promising attempt to create truly multi-disciplinary, multi-sectoral cooperation that can unite research, policy and praxis in a learning cycle. Future efforts to address uncertainty may use different methods, but they will probably address many of the same questions that the AM discipline requires one to raise. As shown in the case study below, each application rarely follows the "classic" template presented above, but the basic principles of cyclic, structured learning prove useful and important.

AM APPLIED ON THE KISSIMMEE RIVER, FLORIDA

The Kissimmee river basin (KRB) is the northern river arm of a hydrological system running from the headwater lakes near Orlando across Lake Okeechobee and down through the Everglades to Florida Bay (Figure 4). Increasing human use and settlement of the KRB collided with severe flooding from hurricanes in the 1940s, resulting in enough political pressure to fund a massive flood control project in the 1960s. The Kissimmee river, formally meandering in winding arcs for 160 km through a 4 km wide marshy floodplain, was straightened into a 10 meter deep channel that sliced through the meanders, shortening it by 70 km. The faster drainage of the deeper river eliminated the hydrological connection with much of the riverine marsh bordering it, decreasing floodplain area by 75 percent (18 000 ha). The massive loss of wetland habitat area and quality resulted in a 90 percent decline in wading bird populations, and eventually repeated episodes of vast algal blooms covering hundreds of square kilometres on Lake Okeechobee signalled the loss of wetland nutrient processing capacity along the KRB. These signs of environmental degradation were so swift and dramatic that within two decades of the project's completion public opinion had surged to authorize spending yet another 400 million dollars to completely reverse the flood control project's hydro- engineering and "un-straighten" the river.

The restoration of the KRB commenced in 1999 with the following goals: re-establishing historic discharge patterns from Lake Kissimmee, acquiring 38,600 hectares of floodplain and watershed land in the Kissimmee Chain of Lakes (the upper basin) and the river valley (lower basin), continuous backfilling of 35.2 kilometers of canal, removal of 2 water control structures, recarving 15.5 kilometers of former river channel (Light and Blann 2000). The scope of such tasks was unprecedented. This was the largest and most expensive attempt to restore the natural structure and functions of a major river in history. However, the lack of knowledge and experience in the design and execution of such re-engineering was the most profound challenge. No one knew how to do this, and engineers as well as policy makers and the public would have to learn to do this as the project progressed in an atmosphere already charged with political intensity after twenty years of acrimonious debate. The key to its surprising success was that some of the core coordinators learned to use this challenge as the catalyst to unite a divided society. The fact that *no one* knew the answer proved to be a benefit when used to bring everyone together as people equally ignorant but equally committed to learn.

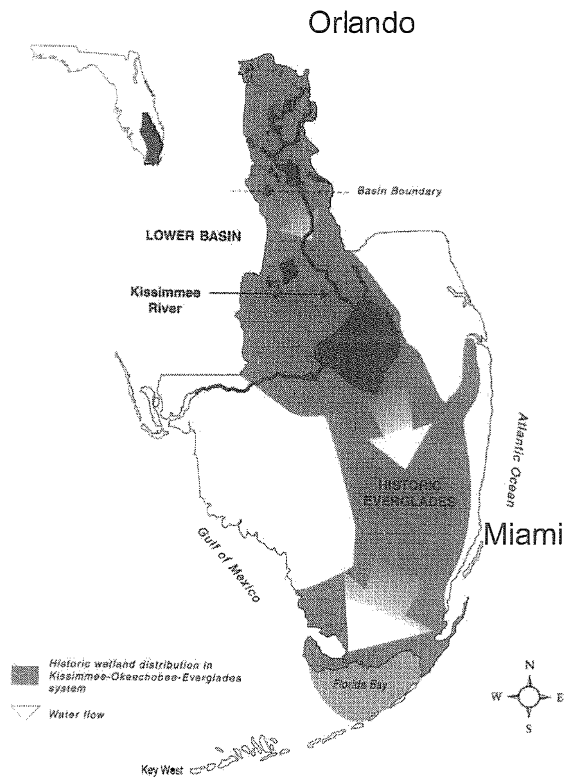


Figure 4: Southern Florida hydrological system extending from the Orlando sub-basin chain of lakes through the Kissimmee river to Lake Okeechobee and down through the Everglades to Florida Bay (after Light and Blann 2000).

Abb. 4: Illustration – Hydrologisches System in Süd-Florida, das sich vom Orlando Wassereinzugsgebiet mit seinen Seen, durch den Kissimmee Fluss zum Okeechobee See und weiter durch die Everglades zur Florida Bucht erstreckt.

Another reason for the success of the restoration is that scientists and managers minimized minor distractions ("putting out fires") and could focus on the big picture of learning new ideas and methods to deal with uncertainty. This broad view emerged from a century of experience wherein periodic disasters and failures forced revision and evolution of the concepts and world-views of professionals as well as of the entire community. Starting with the early settlers in the 19th century the main environmental goals had evolved from "Survival" to "Conquest" to "Water Quantity Control (Flood)" to "Water Quality Control" to "Provision of Recreational and Environmental Values" to "Provision of Ecological Services" to "Building Ecological Integrity" to "Building Resilience to change." The last three goals have emerged as part of the debate about restoring the KRB and provide a wider context in which to explore for new ideas and methods as opposed to the strict political mandate of the 1950s to do anything to avoid flood damage. The restoration coordinators worked to broaden this context by creating a citizen-science learning process that included the entire community in the formulation of goals and issues, the development and revision of research design, and the monitoring and evaluation of experiments and management interventions. These professionals intuitively developed an approach that we recognize in retrospect as adaptive management. The central principle was to keep the community together, not allowing any sector to get out in front of the rest. Therefore, governors and management could not step in front and dictate policy; scientists could not dictate science or secretly move in research directions not accessible to the rest, and NGOs and activists did not jump out from the crowd and derail the entire process. The learning process moved forward in steps, where-in each step was understood by the majority. This began with a scoping process that brought all stakeholders together to define the issues, bound the problem, and set an initial research agenda. It continued as experiments and monitoring provided evidence that provoked rethinking and revision of previous assumptions. For example, a number research and monitoring projects were developed with full public awareness to address critical restoration issues that initially were not understood. A five-year monitored demonstration project helped both scientists and the public to explore the stability of back-filled soils. No one had straightened a river before, so there was great apprehension that the river would simply remove any soils added to re-introduce meanders and curves. Further insights into soil and water dynamics were added by a three-year project of math and computer modelling of soil and river mechanics. A multi-year project using weirs in the floodplain to test ideas about restoration at small scales helped to determine what hydrological regimes might contribute to re- establish pre-channelization hydrology. If the project coordinators sensed political tension because research experiments were not accessible enough to the public, then they launched an educational campaign to describe scientific experiments and findings and open debate as to how to interpret the results and what to do next. On more than one occasion the input of public opinions and values provided challenges that improved research questions and the restoration methods derived thereby.

One critical lesson is that methods of research or decision-making do not always work even if they are superior approaches developed from long traditions of testing. Superior methods work when applied in the right context. In the case of the KRB, good methods were developed partly as a result of a good environmental and political context. This does not diminish the achievement of the project coordinators but rather clarifies the responsibility of anyone contemplating using adaptive management approaches. Methods must be developed *within* the ecological, economic, and socio-political context of the river basin, otherwise any one of these three factors can stall or derail the process. As Light and Blann (2000) conclude:

> *"...resilience in the social arena was buffered by a process of slow, steady, science-based evaluation and public discussion of alternatives and experimental results... The explicit recognition of resilience as a goal, the precautionary and proactive approach taken by project leadership and restoration supporters, and the resilience of the Kissimmee floodplain ecological system itself have all allowed for the possibility of managing for resilience in the Kissimmee basin. The Kissimmee River restoration goal was achieved before degradation of the ecological system had reached crisis proportions or become irreversible, constraining opportunities for adaptive experiments."*

ADAPTIVE DIALOGUES IN EUROPEAN RIVER BASINS

European river management faces rising challenges from direct and indirect impacts of Climate Change (CC) and anthropogenic activity. Average atmospheric temperature elevation threatens to drastically reduce steady melt water inputs and to boost Rhine river flood peak levels 20 percent higher that previously experienced, and more intense rain volumes can increase the frequency of local and basin scale flood events (Sendzimir et al. in review). At the same time, human modification of land use and land cover can intensify runoff, thereby aggravating problems of water quality, drought and flooding. These problems persist despite substantial investments in the construction and maintenance of river engineering defence systems. In this section we examine two programs that attempt to integrate research, policy and management actions into comprehensive approaches to address uncertainty. Engineering cannot simply be abandoned, but we need rigorous scientific foundations to integrate ecological, economic, agricultural and social factors in our redesign of river basins.

Netherlands – Room for the River Program

In choosing long-term strategy for the Rhine River, the Dutch are reconsidering the benefits of conventional traditions of hydro-engineering not only because it seems inadequate to address rising flood levels. They ask why should we invest in raising and reinforcing dikes if it also threatens ecological and cultural values? (Dijkman and Heynert 2003, von Stokkom and Smits

2002). Hydro-engineering also appears less and less cost-efficient because of declining cost/benefit ratios to maintain high levels of water management organization and infrastructure (Boot and van Ast 2004).

A new Dutch initiative called "**Room for the River**" is a set of management strategies that imitate natural processes which sustain the key factors of river basin resilience: flood absorption capacity, biodiversity, basin morphometry). One strategy *Cyclic Rejuvenation of the Floodplain* (Baptiste et al. 2003) aims initially to mimic the functioning of flood surges as a part of a longer campaign to increase the basin's capacity to absorb and utilize floods. Flooding torrents often expand the basin's capacity to absorb flood volumes by blowing out sediments, lowering floodplain elevation and increasing the river's cross-sectional area. The potential for water to move through the basin is also increased when flooding creates new side channels and lowers the coefficient of roughness by removing vegetation and substrate and setting the ecological clock back to early successional stages. Flooding periodically reverses the steady rise in elevation created by the normal accretion (1 centimeter per year, on average) of organic matter from wetland production. This strategy is currently being tested for its impact on biodiversity in pilot-scale demonstrations that create secondary channels and lower floodplain elevations (van der Molen et al. 2002).

Green Rivers is another strategy within the Room for the River initiative which aims to increase river discharge capacity by diverting flood volume excesses to the vegetated "green" areas behind the dikes. These "back swamps" offer alternative, parallel paths for flooding as well as storage areas that increase the landscape's retention capacity during droughts. Both strategies require substantial investments in time, negotiations and money in order to create an orderly social dialogue that allows those who live or use the floodplain to move to higher ground without undue personal loss. The Room for the River Initiative will employ a range of activities (Figure 5) to open the floodplain such that flooding can eventually be the dominant process that structures the river basin's landscape and ecological communities. This initiative acknowledges (Duel et al. 2003) that it must proceed in a careful, deliberate and very transparent way and with sufficient scientific rigor to justify the first reversal of centuries long traditions of "winning the land" from areas that are normally flooded in the Netherlands. As such, an Adaptive Management model of citizen-science dialogue would be appropriate to allow comprehensive discussion of how the Room for the River program can address all ecological, economic and social factors over the coming century.

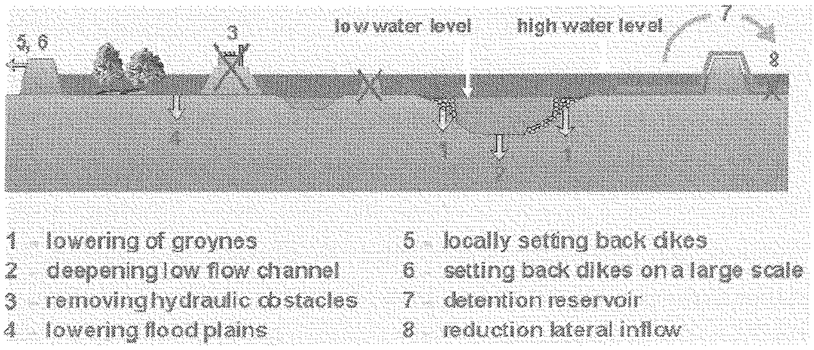


Figure 5: Actions planned for the Dutch "Room for the River" program over the next decades along the Rhine river (source: *www.ruimvoorderivier.nl*)

Abb. 5: Geplante Aktivitäten für das Holländische "Platz für den Fluß" Programm für die kommenden Jahrzehnte entlang des Rheins (Quelle: *www.ruimvoorderivier.nl*)

The Netherlands has explored AM-type decision frameworks for as long as any other nation, and will probably do so on the Rhine. However, in the Netherlands using AM ironically represents a challenge in that many people are frustrated with discussion processes. They are wary of anything that can delay action as discussion endlessly plods on. Hopefully this frustration will spur the evolution of new innovations in AM, with new mechanisms of assessment and management action that produce concrete results which deepen rather than prolong debate.

Hungary – Renaturalization of the Tisza Floodplain

Government, academia and NGOs in Hungary are coming to the same conclusion as the Dutch: hydro-engineering cannot, by itself, maintain flood safety and stop the degradation of the biological and cultural heritage of the Tisza River Basin (TRB). The prospect of yet another round of massive dike investment after failure of defense infrastructure during the last major flood in 2001 forced a fundamental re-examination of alternatives. Several years of discussion produced a new flood protection initiative in the TRB, the *new* Vasarhelyi Plan (Váradi 2001). This initiative is named after the engineer who fathered the original reshaping of the Tisza in the 19^{th} century as official façade to maintain some solidarity with past engineering traditions. However, for the first time a flood crisis response does *not* recommend raising and reinforcing dikes. Instead, the potential to remove the dikes and use certain areas of the original floodplain for storing flood volume is being exploited. This was never an easy consideration for water engineers in Hungary, because dike failure leading to loss of life was the fastest way to lose one's job and even end up in jail. But the series of dike failures over the past century pointed only to on-going failure as Climate Change and other factors increased flood frequency and intensity.

By utilizing the floodplain for flood control, the new Vasarhelyi Plan raises a new set of questions. Should the floodplain be only used for flood control? What are the opportunities to re-establish the traditional roles of flooding to store water on a dry landscape and to sustain biodiversity as well as fish productivity? And where and how should people live and earn a living if they must move off the flooded parts of the plain? Beginning in 2002 a new research initiative (Kovacs 2000), sponsored and coordinated by WWF-Hungary, set out to answer some of these questions in the middle reaches of the Tisza around the village of Nagykörü. It aims to explore questions related to ecology, agriculture and fisheries as part of a comprehensive assessment of the impacts of re-connecting the floodplain with the Tisza river channel. We consider now some of the key elements of this program within the context of proposing how adaptive management could serve as a framework to link these research projects with management interventions and efforts to start local floodplain-based enterprises.

Nagykörü – study site

The village of Nagykörü is located in the middle reaches of the Tisza river, some 22 km north-east of Szolnok, the regional urban center. This village of some 10 000 people sits on a ridge of high ground extending along an east-west axis to within a few hundred meters of the Tisza river as it swings in a wide arc from North to West. The village ridge is surrounded by low areas that, prior to hydro-engineering, were flooded relatively frequently (almost annually). The spatial heterogeneity of depressions of different depth in the floodplain offered a rich diversity of water storage potential. In the centuries before the Industrial Revolution, local people developed a culture that used this dynamic water storage potential to sustain a rich and diverse landscape mosaic that supported a variety of uses: orchards, grazing meadows and fish ponds.

People today would scarcely recognize the TRB landscape and culture before the Industrial Revolution. Far from its current depressed aspect, the economy of the TRB was thriving, selfsufficient and rich enough to export fruits, vegetables, timber and fish (Dr. Veres Nandor[1], pers. Comm.). However, our modern sense of diversity, tuned to the 3 or 4 varieties of any domestic fruit a supermarket might offer, would be amazed to find the hundreds of varieties of fruit and nuts traditionally grown in the TRB. Local varieties of apple (402) and pear (470) have been officially registered, but the unregistered varieties run well past a thousand for each (Suryani 1987, 1988, 1992, 2002; Bellon 2003). The same holds for walnut trees, whose timber amply provided local needs for fine quality lumber for furniture.

Such extreme diversity in agricultural production is neither an extravagant gesture nor some slavish adherence to tradition. This ancient practice was developed over centuries in the TRB (Andrásfalvy 1973, Molnár 2003, Paget 1855, Tóth 2002, Bellon 2003). It represents a strategic response by which people have adapted to the variability in Nature in every region of the globe since the Neolithic era (McNeely and Scherr 2003). Plants and people must contend with severe fluctuations in water within the TRB, from sudden and intense flooding lasting for weeks over hundreds of square kilometers to droughts that may last for years over the entire basin. These sudden flows and slow ebbs produced a huge variety of flooding durations over the different elevations on the floodplain (Figure 6), and the web of sluices (*fok* in Hungarian) connect the many depressions in the landscape with the river channel, linking fish nursery areas with the river.

A diversity of capabilities has been the traditional answer to the uncertainty inherent in such wide swings from wet to dry in river valleys, with all the variety of changing opportunities and challenges in between. Hillside farmers in Peru might plant 150 varieties of potato in small (30 hectare) farms in the Andes (Scurrah et al. 2000, Roach 2002), and farmers in Bangladesh have developed thousands of rice varieties to deal with the vagaries of flooding and dispersion of the Bhramaputra and Ganges rivers in their delta (Nishat Ainun[2], pers. Comm.). Floodplain farmers along the Tisza developed fruits that could survive relatively short durations (up to two weeks) and intensities of flooding and drought (Bellon 2003). They also developed a local corn variety so well adapted to a short growing season, that one could plant it after the annual spring floods and still harvest a mature plant by autumn. In comparison to the pesticides and fertilizers required by the relatively few global varieties that consumers from the UK to Austria recognize, these local TRB varieties have proven far more robust against insect pests and diseases, and did

[1] Mayor, village of Nagykörü
[2] IUCN, Dhaka, Bangladesh

not require as much pruning or intensive care (Siposs and Kis 2002). However, they are rapidly being replaced by continental and global varieties. For example, Hungarian consumption of local varieties of cherries has declined from eighty percent to less than thirty percent due to the domination of the Hungarian market by the *germersdorfer* sweet cherry, a variety sold across the EU (Surány 2002.)

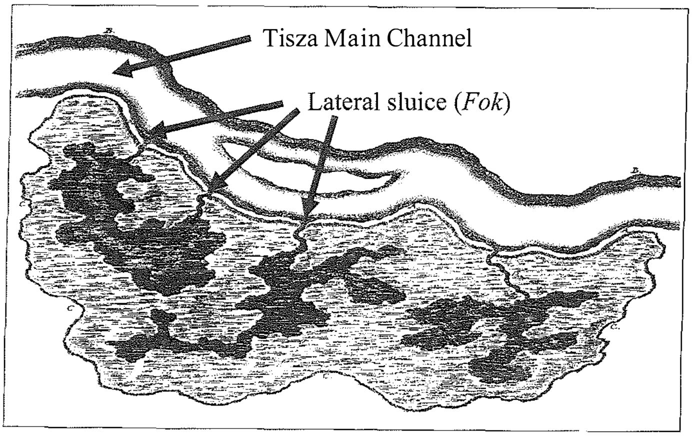


Figure 6: Simplified illustration of the Tisza river main channel with lateral connecting channels (*fok*) to floodplain depressions of different depths producing a diversity of different flooding depths and durations. (Illustration courtesy of Dr. J. Hamar, Tisza Klub, Szolnok, Hungary)

Abb. 6: Illustration – Vereinfachte Illustration des Hauptkanals der Tisza mit Seitenarmen und Auensenken unterschiedlicher Tiefen, die eine Vielfalt verschiedener Überschwemmungstiefen und -dauer erzeugt. (Illustration von Dr. J. Hamar, Tisza Klub, Szolnok, Hungary)

Adaptive framework to re-establish river basin culture

Decades of scientific research have examined the natural and social history of the Tisza basin. This scientific legacy offers a wealth of information, but many local people mistrust scientists when they see how few concrete results all this scientific research has yielded. Some stakeholders threaten not to cooperate with scientists in the future, saying that the scientists only stay long enough to get the information they need to further their careers but never engage in long-term efforts to convert new insights into policies or structures that improve peoples' lives. The WWF research initiative attempts to address this admonition by working in parallel on both the ecological and economic potential created by reconnecting the floodplain to the Tisza river channel. This potential includes traditional fruit orchards, fish ponds, and wet meadow grazing by ancient breeds of cattle (Figure 7).

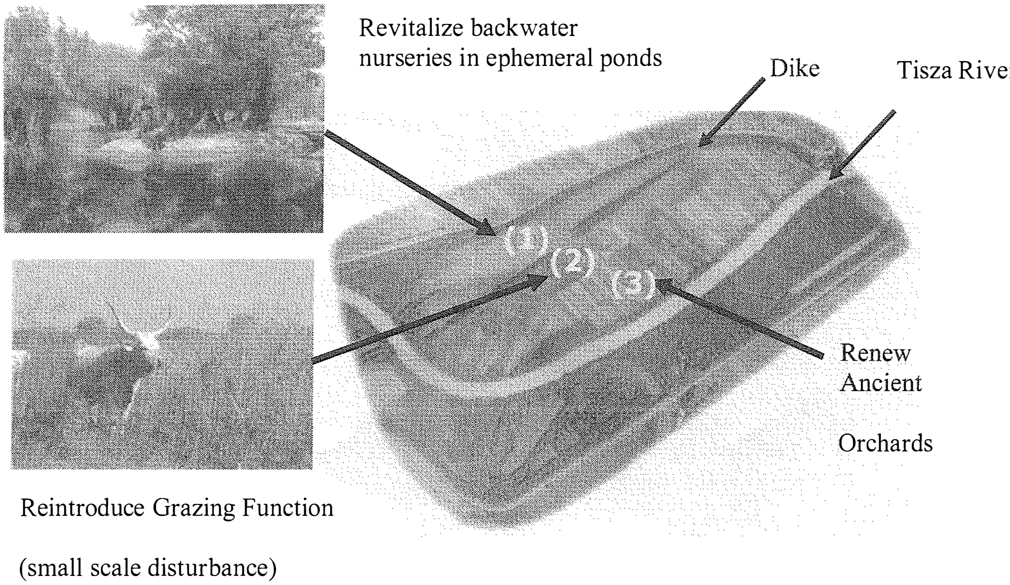


Figure 7: Three traditional uses of the Tisza river floodplain that will be tested in pilot studies sponsored by WWF-Hungary (Illustration courtesy of Peter Balogh, Nagykörü, Hungary)

Abb 7: Drei traditionelle Formen der Nutzung der Tisza Auen die in, von WWF-Ungarn geförderten, Pilotstudien getestet werden.

The challenge for this participatory science-policy initiative is that our present understanding is insufficient to re-establish a functioning society, agriculture and ecosystem in a naturalized Tisza river basin. Despite much research we still have an incomplete view of what ecological services and functions existed and what humans did to sustainably exploit those opportunities. NGOs and local citizens strongly believe an economically viable orchard culture did exist and can exist again on a re-naturalized Tisza floodplain (Balogh 2003). However, it will take peer-reviewed scientific experimentation to reduce doubts about such claims. The fundamental point is that even if we had a complete view, the past cannot simply be resurrected. The context never remains the same. The landscape and its human and animal communities change and evolve. Efforts to try to freeze the landscape context in some arbitrary vision of the past are doomed to failure, because we do not know what species, behaviours, phenotypic expressions or new arrangements will thrive best in a context that has shifted from the past. The landscape may not be very different from what was, but it will be different. And since society is changing far more rapidly than the ecosystem, we need a framework to integrate our research, policies and practices to adapt to the evolving context of changing society and ecosystems. Such a framework would allow scientists and NGOs to collaborate in testing alternative hypotheses about what kind of orchard culture will thrive when a flooding regime is re-established on the Tisza floodplain.

Adaptive management (AM) offers such a flexible framework, but it can be modified to increase public participation and engage all local stakeholders, even those who mistrust professional scientists and policy makers. One way to open the process and make it more transparent is to use it to provide tools to measure progress. AM does this first and foremost by offering structure. It provides a set of activities in an iterative cycle, and the pause for each activity signals how far the community discussion has gone. The second tool is to use the AM process to define issues and problems and formulate policies to test hypotheses as to why the problem exists. How these tests of hypotheses increase understanding is another measure of progress. The third tool is to use the AM process to identify and then measure indicators of progress toward achieving goals. We propose an AM approach below that allows participants to derive and use all the tools for measurement: graphic maps of the whole system, key variables, goals, policies to achieve those goals, and indicators of successful performance by policies.

Our experience in applying AM in the Odra river valley in Poland (Sendzimir et al. 2003) shows that we can use the scoping exercises at the beginning in ways different from the "classic" AM previously described in Figure 3. We did begin with problem articulation and identified the key variables and their interactions that are involved in the problem(s) of concern to stakeholders. Stakeholder-driven discussion helped connect the variables into a graphic map of the interactions that are the skeleton or structure of the system (mental model map *sensu* Sterman 2000). However, since this was not a citizen-science dialogue to prioritise research, the assessment phase did not proceed to articulate different hypotheses as alternative explanations for how problems arose or why they persist. The broad initial goal of stakeholders was to agree on a regional vision of sustainability that highlights what they should focus on in order to encourage farmers to engage in more environmentally friendly practices. Most of these stakeholders were officers and volunteers in environmental NGOs more interested in identifying the policies and practices they should apply to improve environmentally friendly industries. They were less interested in researching underlying mechanisms than in identifying courses of action and how to measure the progress of these interventions in achieving sustainability of the region. So the AM process focused the discussion to help stakeholders agree on the key variables and indicators of change in those variables.

While the Odra river valley AM process continues, reflection on our experience to date suggests the following structure for an AM framework to help people identify and use sustainability indicators (Figure 8).

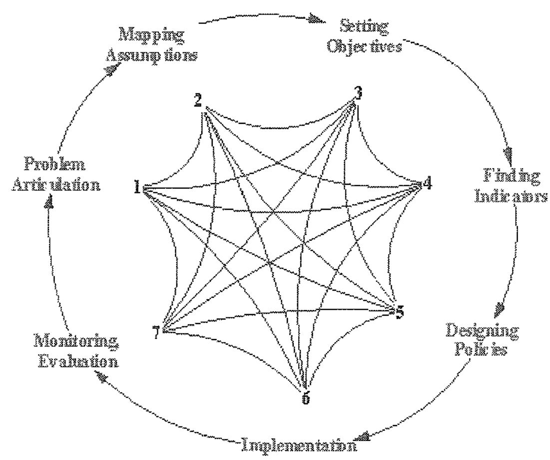


Figure 8: Adaptive management framework revised following system dynamics modelling approaches of Sterman (2000) to explicitly incorporate performance indicators.
Abb. 8: Adaptive Management System basierend auf dem Modellansatz von Sterman (2000), mit eingearbeiteten Leistungsindikatoren.

We first note that mental maps help to develop an overview but they do not replace a common vision. The vision of where a community *wants to be* is the overarching goal against which all actions and ideas can be measured. This AM framework mandates that directly after mapping the system such a vision be pursued as part of setting objectives. This clarifies the identification of indicators, because key variables for which we determined indicators are considered important only in relation to objectives. Therefore, making objectives explicit speeds the identification of indicators that clearly relate to the community's vision and goals, not merely to variables that are prominent and easy to measure (Magnuszewski et al. *in review*).

Applying the AM framework in the Tisza river basin

Achieving a sustainable river basin culture requires a framework that allows scientists and stakeholders to collaborate in research and in revising policy and local practices. In a social context that is suspicious and sometimes antagonistic to outside academics, the AM process should offer the means for all parties to jointly investigate alternative hypotheses as to what agriculture is functionally viable in a re-naturalized floodplain, to intervene and act, and to measure progress. We propose that our Odra river AM experience, while preliminary, still suggests that local stakeholders can provide solid experience and support if engaged in all phases of the process, especially monitoring of indicators of policy performance. Local stakeholder experience can prove vital to experiments that explore how to establish an economically viable culture on a re-naturalized floodplain. Key research tasks include: testing what varieties of fruit and nut trees can withstand different degrees of flooding and drought, what sluice and channel morphologies establish hydroperiods that support productive fisheries, what breeds of cattle can thrive on floodplain wet meadows. Such questions will provide the most compelling evidence to stakeholders and policy makers of the potential offered by re-naturalizing rivers. Confidence about economic (and hence social) development will create a much more supportive atmosphere for natural scientists to examine the more esoteric ecological impacts (Table 1) of re-establishing river floodplain hydroperiods. However, AM also offers the chance for such questions to become more understandable when a wider portion of the community has participated in the framing of the questions and the field monitoring of the experiments

Table 1: Factors to monitor for evaluation of ecological impacts of re-establishing hydrological connections between the floodplain and the river channel (after Schiemer, F. and G. Janauer (1994).

Ecosystem Structure	Ecosystem Function
–Geomorphology •Floodplain elevation, cross-sectional area, –Patch structure •Distribution of Habitat sizes (area) and inter-patch distances, –Ecotones (pattern, packing) •Pattern – type, length, curvature, perimeter/area ratio •Packing - density of ecotones, –Habitat connectivity •Degree to which size, proximity and pattern link habitats, –Community structure •Animals - Guilds •Plants and Animals - Species composition	–- Patch Dynamics •Distribution of Habitat sizes (area) and inter-patch distances, - Processes •Production/Respiration •Nutrient and Sediment cycling and movement –Hydrological connectivity •Floodplain and channel(s) –Community Dynamics •Animals - Guilds •Plants and Animals - Species composition

The AM process must also examine issues wider than local ecology and economy however, since it is not yet determined whether local production should support local consumption or must also generate income from export. Such questions expand the range of inquiry to include institutions, markets, and ecological processes that operate at scales larger than the village of Nagykörü. For example, defining the scope (including mental mapping) of factors that influence sustainability in the Nagykörü area of the Tisza river basin, should address institutions such as EU, national and provincial regulations, markets and distribution networks at different scales, and the potential impacts of climate change on regional precipitation and river dynamics.

CONCLUSION

No system of analysis, policy, or practice will ever eliminate surprise and uncertainty Innovation and novelty as well as wicked problems emerge without cease from evolving systems of nature and humanity, and will continue to do so. Our understanding of complexity suggests that "control" and "certainty" are romantic notions born on the rising tide of optimism of the Industrial Revolution. Radical and profound change from climate and technology (genetic engineering), to name only a few sources, will certainly surpass our current imagination of how the environment and society can reconfigure in unprecedented ways in the next few decades. Our responsibility to address the impacts of evolution through new ways of learning, managing, and discussion must keep this uncertainty from being the basis of apathy. Adaptive Management offers a framework to meet that challenge by integrating research, policy and practice. AM offers a window to how democratic action might operate in a technologically complex society, allowing people from all relevant philosophies, trainings, political classes, and organizations to share experience, learn together, devise the policies and practices that allow socio-ecological systems to adapt better to change. Applications of AM in river basins such as the Tisza should generate the experimental evidence needed to found new forms of agriculture, fisheries as well as new understanding of riverine ecology.

REFERENCES

Andrasfalvy, B. (1973) A sarkoz osi arteri gazdalkodasa. No. Vizugyi Torteneti Fuzetek. Budapest. pp. 52-53

Balogh P. (2003) Árvízvédelem és gazdálkodás. In: Tóth A. (szerk.): Tisza-völgyi tájváltozások. Kisújszállás. Alföldkutatásért Alapítvány, 127-141.

Baptiste, M.J., Penning, W.E., Duel, H., Smits, A.J.M., Geerling, G.J., Van der Lee, G., Van Alphen, J.S.L. (2003). "Assessment of cyclic floodplain rejuvenation on flood levels and biodiversity in the Rhine river." *River Research and Applications* in review.

Bellon, T. (2003) A Tisza néprajza. Ártéri gazdálkodás a tiszai Alföldön (Ethnography of Tisza. Floodplain management on Tisza-plain).

Boot, S.P., van Ast, J.A. (2000). Socio-economic evaluation of different alternatives for flood protection within the rivierenland-project. IN Proceedings of EGS XXVII General Assembly - Flood risk and vulnerability assessment in river basins, Nice, France, Copernicus Systems + Technology GmbH

Botári I. and Károlyi, Zs. (1971). A Tisza szabályozása 2. Rész. (1846-1879) - The regulation of River Tisza: Phase 2. (1846-1879). First ed. Budapest, Hungary

Broecker, W. S. 1996. (1996). "Thermohaline circulation, the Achilles heel of our climate system: will man-made CO2 upset the current balance?" *Science* 278:1582-1588.

Checkland, P. B. (1981). Systems Thinking, Systems Practice. John Wiley, New York, New York, USA.

Checkland, P., and J. Scholes. (1999). Soft Systems Methodology In Action. John Wiley, New York, USA.

Craig, W. J., T. M. Harris, and D. Weiner, editors. (2002). Community Participation And Geographic Information Systems. Taylor and Francis, London, UK.

Danny, R., Danziger, L. (2000). The Year 1000: What Life Was Like At the Turn of the First Millennium. ed. Back Bay Books, Boston, Mass., pp.240.

Davies, N. (1996). Europe: A History. ed. Harper Perrenial, New York

Dijkman, J., Heynert, K.V. (2003). Changing approach in flood management along the Rhine River in the Netherlands. IN Dealing with Flood Risk. M. Marchand, Heynert, K.V., van der Most, H., Penning, W.E.(Eds.) Delft University Press. Delft Hydraulics Select Series 1/2003 Delft; 23-34.

Duel, H., Penning, W.E., Haasnoot, M., Klijn, F. (2003). Ecological flood managment strategies for the rivers Rhine and Meuse in the Netherlands. IN Proceedings of Towards natural flood reduction strategies, Warsaw, Eco-Flood Network

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B. (2002). "Resilience and sustainable development: Building adaptive capacity in a world of transformations." *Ambio* 31 (5), 437-440.

Gunderson, L.H., Holling, C.S. (2002). Panarchy: Understanding Transformations in Systems of Humans and Nature. ed. Island Press, Washington, D.C.

Gunderson, L.H., Holling, C.S., and Light, S.S., Ed. (1995). Barriers and Bridges to the Renewal of Ecosystems and Institutions. Columbia University Press, New York.

Gunderson, L.H., Pritchard, L., Ed. (2002). Resilience and the Behavior of Large-Scale Ecosystems. Island Press, Washington, D.C..

Halcrow Group, Ltd. (1999) Feasibility study of flood control development in Hungary. No. Vituki Consult Plc. Budapest. pp. 6

Hamar, A. Sarkahy-Kiss and J., Ed. (2002). Ecological Aspects of the Tisa River Basin. Tiscia Monograph Series. Pro Europa League & Tisza Klub, Targu Mures-Szeged-Szolnok.

Hamar, J., Sakarny-Kiss, A. (1999). The upper Tisa valley: Preparatory proposal for Ramsar site designation and an ecological background. ed. The Tisza Klub, Szeged, Hungary

Haraszthy, L. (2002) Conservation of unique natural values in Hungary. No. WWF Bulletin No. 6. Budapest. pp. 4

Hilborn, R. (1987). "Living with uncertainty in resource management." *North American Journal of Fisheries Management* 7,1-5

Holling, C.S. (1986). The resilience of terrestrial ecosystems: local surprise and global change. In Sustainable Development of the Biosphere. W.C. Clark and R.E. Munn(Eds.) IIASA and Cambridge University Press. Cambridge, U.K.

Horvath, G., Kisgyorgy, S., Sendzimir, J., Vari, A. (2001) Flood Risk Management Policy in the Upper Tisza Basin: A System Analytical Approach. Case Study Report.Report No. IIASA. Laxenburg, Austria. pp. 39.

IPCC (2001). Third Assessment Report: Climate Change 2000: The science of climate change. In J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White(Eds.) Cambridge University Press. Cambridge, UK.

Jolánkai, G. (2002). On the results so far of the Tisza River Project: Real-life scale integrated catchment models for supporting water- and environmental management decisions. IN Proceedings of Natural Attenuation of Metals Along the Tisza River-Floodplain- Wetlands Continuum, Budapest, OTKA-MTA-NSF

Juhász, Á. (1987). Évmilliók emlékei. Magyarország földtörténete és ásványi kincsei. (History of the last million years. Mineralogy and geological history of Hungary). ed. Gondolat Kiadó, Budapest, pp.532.

Kay, J., H. Regier, M. Boyle, and G. Francis. (1999). An ecosystem approach for sustainability: addressing the challenge of complexity. *Futures* 31(7):721–742.

Kovacs, Z.C. (2000) Revitalisation project of the ancient flood-plain agriculture of the Tisza river. Local government of Nagykoru. pp. 13

Kovacs, Z.C. (2003). Sustainability along the Tisza river. M.A. thesis, Oxford Brookes University, Budapest: pp. 88.

Light, S., Blann, K. (2000) "Adaptive Management and the Kissimmee River Restoration Project" Collaborative Adaptive Management Network, Accession Date: 2004. Website address: http://www.iatp.org/AEAM/.

Linerooth-Bayer, J., Vári, A. (in review). "Floods and loss sharing: A clumsy solution from Hungary." *J of Risk Management*

Magnuszewski, P., Sendzimir, J., Kronenberg, J. (in press) Conceptual modeling for Adaptive Environmental Assessment and Management in the Barycz Valley, Lower Silesia, Poland *Int. J. Environ. Res. Public Health*

McNeely, J.A., Scherr, S.J. (2003). Ecoagriculture: Strategies to feed the world and save wild biodiversity. Island Press, London.

Molnar, G. (2003). Arteri gazdalkodas Magyarorszagon. IN Proceedings of Szovetseg II evfolyam 2 szam 17 Januar 2003 pp.6.

Odum, H.T. (1996). Environmental Accounting: Emergy and Environmental Decision Making. First ed. John Wiley & Sons, New York, pp.370

Ostrom, E. (1999) Coping with tragedies of the commons. *Annu. Rev. Polit. Sci.* 2, 493 – 535.

Paget, J. (1850). Hungary and Transylvania with remarks on their condition, soical, political, and economical. ed. Arno Press, New York

Parmesan, C., Yohe, G. (2003). "A globally coherent fingerprint of climate change impacts across natural systems." *Nature* 421: 37-42.

Pecher, I., Stoiko, S. and Kichura, U. (1999). Conception for the Regeneration of the Upper Forest Boundary and for the Optimization of Hydrological Regime in the Ukrainian Carpathians, 1997. In The Upper Tisa Valley: Preparatory Proposal for Ramsar Site Designation and an Ecological Background. J. Hamar and A. Sárkány-Kiss(Eds.) Tisza Klub. Szeged. 207-213.

Peterson, G., G.A. De Leo, J.J. Hellmann, M.A. Janssen, A. Kinzig, J.R. Malcolm, K.L. O'Brien, S.E. Pope, D.S. Rothman, E. Shevliakova, and R.R.T. Tinch. (1997). "Uncertainty, Climate Change, and Adaptive Management." *Conservation Ecology [online]* 1 (2):pp. 4. Available from the Internet. URL: http://www.consecol.org/vol1/iss2/art4

Pokorný, J., Ripl,W. Et Eiseltová,M. (1998). Impacts of Deforestation and Drainage on Climate: Landscape Management and Policy Implications. IN Proceedings of WaterTech - conference promoting technology, science and business in the water industry, Brisbane, Australia, 1-12.

Pretty J. N., I. Guijt, I. Scoones, and J. Thompson. (1995). A Trainer's Guide For Participatory Learning And Action. IIED, London, UK

Renn, O., Webler, T. (1995). A Brief primer on Participation. Philosophy and Practice.IN Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse. Thomas Webler Ortwin Renn, and Peter Wiedemann (Eds.) Kluwer. Dordrecht.

Renn, O., Webler, T. Wiedermann, P. (1995). A Need for Discourse on Citizen Participation: Objectives and Structure of the Book.IN Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse. Thomas Webler Ortwin Renn, and Peter Wiedemann (Eds.) Kluwer. Dordrecht.

Ripl, W. (1995). "Management of water cycle and energy flow for ecosystem control - the Energy-Transport-Reaction (ETR) model." *Ecological Modelling* 78:61-76.

Rittel, H., Webber, M. (1973). "Dilemmas in a General Theory of Planning." *Policy Sciences* 4:155-159.Dilemmas in a General Theory of Planning.

Roach, J. (2002) "Saving the potato in its Andean birthplace" National Geographic News, Accession Date: Website address: http://news.nationalgeographic.com/news/2002/06/0610_020610_potato.html.

Schiemer, F., Janauer, G. (1994). "Monitoring rivers and floodplains: Proc. Monitoring of ecological change in wetlands of middle Europe." *Stapfia* 31: 93-107.Monitoring rivers and floodplains: Proc.

Scurrah, M., Canto, R., Zuniga, N. (2003) "Self-sufficiency and sustainability of the native potato cultivation in the community of Quilcas, in the Mantaro Valley, in the central Andes of Peru" Grupo Yanapai, Accession Date: 2003. Website address: http://www.unu.edu/env/plec/cbd/abstracts/Scurrah.doc.

Sendzimir, J., Gottgens, H., Pokorny, J. (in review). "Assessing multiple scales of climate change impacts on northern-hemisphere freshwater wetlands." *Climatic Change.*

Sendzimir, J., Light, S., Szymanowska, K. (1999). "Adaptive Understanding and Management for Floods." *Environments* 27 (1): 115-136.

Senge P. (1990). The Fifth Discipline: The Art And Practice Of The Learning Organization. Doubleday, New York, New York, USA.

Siposs, V., Kis, F. (2002) Living with the river: LIFE-Nature project in the Tisza floodplain. No. WWF Hungary. Budapest. pp. 24.

Slocum, R., L. Wichart, D. Rocheleau, and B. Thomas-Slayter, editors. (1995). Power, Process And Participation: Tools For Change. Intermediate Technology Publications. Exter, UK.

Sterman, J. (2000). Business Dynamics. First ed. Irwin/McGraw Hill, New York.

Sterman, J. (2002). "All models are wrong." *Sys. Dyn. Rev.* 18:pp. 501-531.

Sümegi, P (1999). Reconstruction of flora, soil and landscape evolution, and human impact on the Bereg Plain from late-glacial up to the present, based on palaeoecological analysis.IN The Upper Tisa Valley - Preparatory proposal for Ramsar site designation and an ecological background. J. Hamar and A. Sárkány-Kiss(Eds.) Tisza Klub for Environment and Nature. Szolnok, Hungary.

Surányi D. (1987) Magyar biokertek a XII:században. Bp. Natura

Surányi D. (1988) Régi magyar ellenálló gyümölcsfajták. Bp. Mezőgazdasági Kiadó Planétás Gmk.

Surányi D. (1992) Magyar gyümölcs múltban és jelenben. Bp. Kertészeti és Élelmiszeripari Egyetem

Surányi D. (2002) Gyümölcsöző sokféleség. Cegléd. Akcident Nyomdaipari Kft.

Szlavik, L. (2000) "The Development policy of flood control in Hungary" Accession Date: 2003. Website address: http://www.fzki.uniag.sk/EMRI.2000/Abstracts/Szlavik.html.

Toth, F. L. (1988). Policy exercises. *Simulation & Games* 19:235--276.

Toth, J. (2002). A tiszai cianszennyeezes. ed. Rednszerszemleletu elemzes, Szeged

van de Kerkhof, M. (2001). *A survey on the methodology of participatory integrated assessment.* IIASA Working paper IR-01-014, Laxenburg, Austria.

van der Heijden, K. (1996). Scenarios: The Art Of Strategic Conversation. John Wiley, New York, USA.

Van der Molen, D.T., , Buijse,A.D., Jans,L.H., Simons, H.E.J, and M. Platteeuw (2002) Ecologisch rendement van herstel- en inrichtingsmaatregelen. Voor het traject van Lobith tot de Noordzee. No.:2002.032, RIZA (Rijksinstituut voor Intergraal Zoetwaterbeheer en Afvalwaterbehandeling). Lelystad.

Van Stokkom, H.T.C., Smits, A.J.M. (2002). Flood defense in the Netherlands: a new era, a new approach.IN Flood Defence 2002. Wu et al.(Eds.) Science Press. New York, 34-47.

Váradi, J (2001) How to Proceed After Floods and Before New Floods? Development of the Vásárhelyi Plan. Hungarian: Ministry of Transportation and Water Management. Budapest.

Vári, A. (2002). "Public involvement in flood risk managment in Hungary." *Journal of Risk Research* 5, 211-214.

Vári, A. & Kisgyorgy, S. (1998). "Public participation in developing water quality legislation and regulation in Hungary." *Water Policy* 1, 223-238.

Vári, A., Linnerooth-Bayer, J., Ferencz, Z. (2003). "Stakeholder Views on Flood Risk Management in Hungary's Upper Tisza Basin." *Risk Analysis* In Press:

Vay, A. Baron (2002). Észrevételek a Tisza és mellékfolyóinak szabályozásáról.IN Tisza-parti jegyzetek, Vége nincs Tisza-szabályozás. Guelmino János(Eds.) http://www.zetna.org.yu/zek/konyvek/48/b9.html. Budapest.

Walters, C.J. (1986). Adaptive Management of Renewable Resources. ed. McGraw Hill, New York.

Walther, G.-R, E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J-M. Fromentin, O. Hoegh-Guldberg and F.Bairlein. (2002). "Ecological responses to recent climate change." *Nature* 416:389-395.

Water, Halcrow (1999) Flood Control Development in Hungary: Feasibility Study. Final Report.Report No. Halcrow Group Ltd. London, UK.

Wu, F. (2000) The Tisza river crises: integrating stakeholder views for policy decisions. YSSP Working Paper.Report No. IIASA. Laxenburg, Austria. pp. 29

ECOLOGICAL MANAGEMENT OF THE RIVERBANKS ALONG THE ENNS (NATIONAL PARK GESÄUSE, STYRIA, AUSTRIA)

NATURRAUM MANAGEMENT DER FLUSSUFER AN DER ENNS (NATIONALPARK GESÄUSE, STEIERMARK, ÖSTERREICH)

Daniel KREINER

Nationalpark Gesäuse GmbH, Leitung Fachbereich Naturschutz und Naturraum, 8913 Weng im Gesäuse 2

ABSTRACT

The Enns River forms the sensitive "backbone" of the National Park Gesäuse. Between the Gesäuse entrance and the weir in Gstatterboden, the Enns is characterized by a very natural state, a highly varied riverbed structure, and particularly strong dynamics. Unfortunately, the various user groups are heavily concentrated along this very stretch of the Enns, placing a range of demands on the green-blue band of water as it winds its way through the mountains. One of the National Park's greatest challenges is to develop a package of measures and implementation strategies that will help minimize current ecological deficits over the medium and long term. The goal is not only to prevent further deterioration, but actually to improve the habitat along the Enns. Three case studies show the different ways the National Park Gesäuse meets the demands on the ecological management of the riverbanks along the Enns.

KEYWORDS: Stream ecology, visitor management, forest conversion, nature-orientated control works, NATURA 2000

ZUSAMMENFASSUNG

Die Enns bildet das sensible Rückgrat des Nationalparks Gesäuse. Zwischen Gesäuseeingang und dem Wehr in Gstatterboden zeichnet sich die Enns durch einen hohen Grad an Natürlichkeit, eine abwechslungsreiche Struktur im Gewässerbett und eine besonders starke Dynamik aus. Leider konzentrieren sich in eben diesem Abschnitt der Enns auch die verschiedensten Nutzergruppen, die das schmale, grün-blaue Band von verschiedensten Seiten bedrängen. Es ist nun für den Nationalpark eine der vordringlichsten Aufgaben, Maßnahmenvorschläge auszuarbeiten und mittel- bis langfristige Handlungsstrategien zur Minimierung bestehender ökologischer Defizite aufzuzeigen. So soll im Endeffekt nicht nur eine Verschlechterung verhindert, sondern auch eine Verbesserung des Lebensraumes an der Enns erreicht werden. Drei Fallstudien sollen das Naturraum-Management des Nationalparks Gesäuse am Ennsufer dokumentieren.

STICHWÖRTER: Fließgewässerökologie, Besucherlenkung, forstliche Umwandlungsmaßnahmen, ökologische Verbauung, NATURA 2000

INTRODUCTION

The Enns River forms the sensitive "backbone" of the National Park Gesäuse. It has its source in the Province of Salzburg (Radstätter Tauern, at the foot of the Kraxenkogel, 1735 m) and drains a catchment area of 6080 km² along a stretch of 254.15 km. Between its source and confluence with the Danube River, the Enns drops 1497 m. This makes the Enns Austria's longest river to both originate and end within the country's borders. The Enns crosses the border between the Greywacke Zone and the Calcareous Alps in the Admont Basin; at the entrance to the Gesäuse. Ice Age moraines forced the river to make its way through the Northern Calcareous Alps. This is accompanied by a rapid change in the river landscape from wide valleys in the Admont Basin to the gorge-like Gesäuse entrance, to a narrow, V-shaped valley bordered by the towering rock faces of the Hochtor chain and the Buchstein. The Hochtor peak lies nearly 1800 m above the Enns.

Between the Gesäuse entrance and the weir in Gstatterboden, the Enns is characterized by a very natural state, a highly varied riverbed structure, and particularly strong dynamics. The fish fauna corresponds to a fast flowing river of the grayling-trout zone. Grayling (*Thymallus thymallus*) and trout (*Salmo trutta f. fario*) together amount to nearly 90 % of the biomass in the Gesäuse Enns (Jungwirth et al., 1996). Also some endangered species have their habitat in the Gesäuse Enns: these are the vairone (*Leuciscus souffia*) and the Ukrainian lamprey (*Eudontomycon mariae*). Both of them depend on the occurrence of gravel and sand bars. There were some shifts in the population structure of the fishfauna in the past. They occurred because of different reasons: sudden water level variation because of hydraulic bore from an upstream hydro power plant, great Cormorant population explosion (Zauner et al., 1999) and disruption of the river corridor.

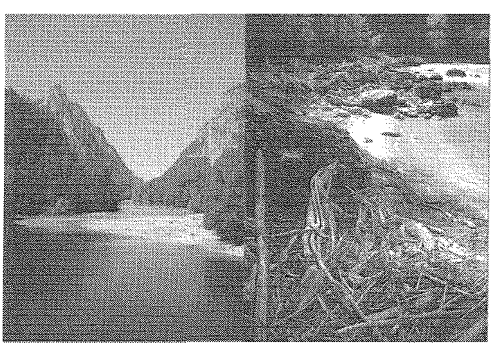


Fig. 1: Enns River (National Park Gesäuse)
Abb. 1: Die Enns im Nationalpark Gesäuse

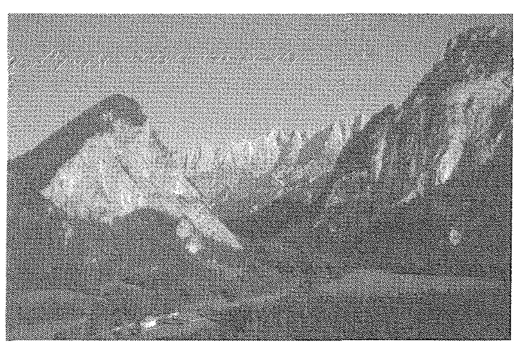


Fig. 2: Gesäuse Entrance and Hochtor chain
Abb. 2: Gesäuse Eingang und Hochtorgruppe

ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

Different anthropogenic changes threaten the highly natural state of the Enns river. Unfortunately, the various user groups are heavily concentrated along this very stretch of the Enns, placing a range of demands on the green-blue band of water as it winds its way through the mountains. One of the National Park's greatest challenges is to develop a package of measures and implementation strategies that will help minimize current ecological deficits over the medium and long term. The goal is not only to prevent further deterioration, but to actually improve the habitat along the Enns.

CASE STUDY 1: SHORE STABILIZATION BRUCKSTEIN

The narrow valley serves as an important W-E traffic link, and the river is therefore bounded by both the railway and the road. During the flooding in 2002, the concave bank on the opposite side of the Lettmairau was so highly eroded that it affected property owned by the ÖBB (Austrian Federal Railways). The directly impacted sections must be stabilized now. Agreement has been reached to make every effort to construct an ecologically compatible passage combined with an improved riverbed structure (coarse rough stone layering, groins).

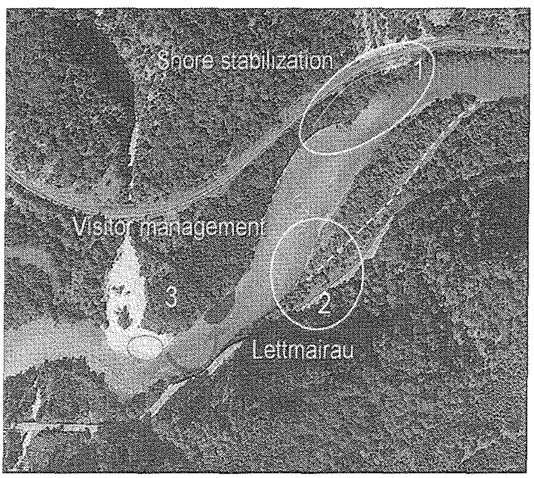


Fig. 3: Location of the case studies (airial photograph)

Abb. 3: Örtlichkeit der Fallstudien (Orthophoto)

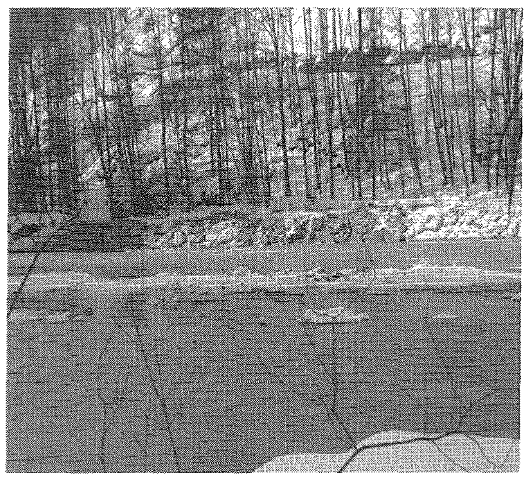


Fig. 4: Shore stabilisation: Rough stone layering, groins under water level

Abb. 4: Uferverbauung: Grobblockschlichtung

CASE STUDY 2: NATURA 2000 MANAGEMENT

In the framework of the above project, an adjoining, dried-out floodwater channel is to once again be provided with water in order to maintain the floodplain dynamics in the Lettmairau. Moreover, a new, calm-water habitat for endangered fish species (vairone, Ukrainian lamprey both Habitat Directive Annex II) and spawning habitats for amphibians are planned.

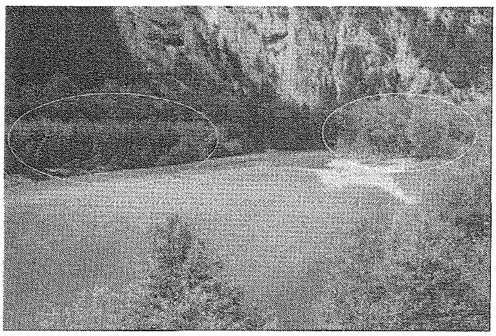


Fig.5: Right: Natural floodplain forest Left: Anthropogenic spruce forest
Abb. 5: Rechts: Natürliche „Weiche Au" Links: Anthropogener Fichtenforst

Across the river is an area ("Krapfalm") where spruce (*Picea abies*) dominates. A long-term goal is to fully replace the anthropogenic spruce forests along the Enns by the site-specific floodplain forests (Salix eleagnos scrub, Salicion albae). Due to its easy accessibility and level terrain compared to the surrounding massifs, every square metre was intensively used in the past. This ranged from "alpine" farming near Krapfalm to intensive forestry. This transformation will primarily involve setting free admixture tree species. The forest management and service is done by the "Steiermärkische Landesforste" (Forest company of the province of Styria).

CASE STUDY 3: VISITOR MANAGEMENT

Gravel banks form an additional key habitat. They provide a substrate for the first pioneer communities that ultimately give rise to riverine forests. From *Calamagrostion pseudophragmitis* to willow bushes to grey alder riverine forests. They not only form potential sites for the highly endangered tamarisk (reintroduction programme for *Myricaria germanica*) but also a habitat for the rare common sandpiper (*Actits hypoleucos*) and numerous ground beetle species (e.g. the highly endangered *Bembidion foraminosum*) or grasshoppers. This particularly sensitive habitat is under heavy pressure from tourism (rafting, kayaking, illegal camping and fire sites). This requires developing and implementing a visitor management plan (information signs, ranger service, etc.)

The first step for all these measures was taken last year in the framework of a survey of the present status, which has already been completed in certain sectors, like vegetation (Kammerer, 2003) and common sandpiper (Zechner, 2003). A future monitoring programme will then serve as a mechanism to control and fine-tune the implemented measures to help ensure that the goals are met.

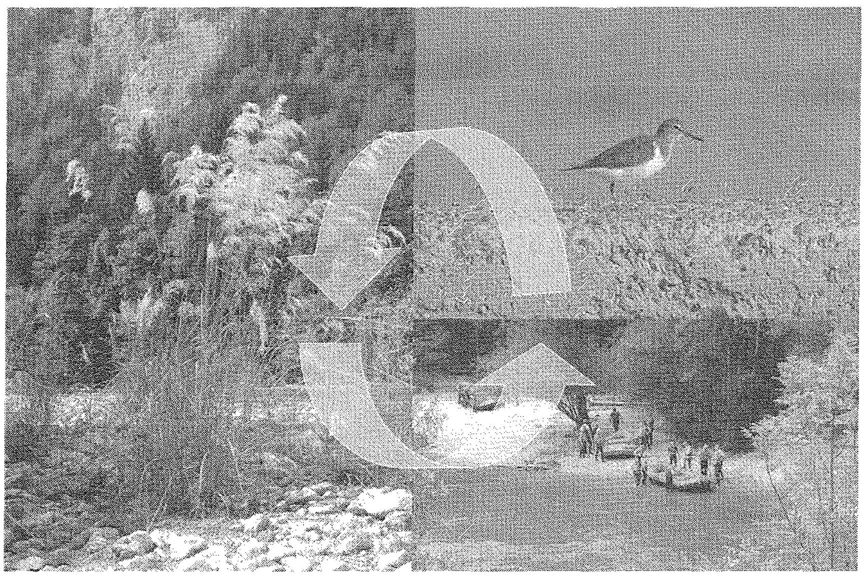


Fig. 6: Calamagrostis pseudophragmites and Actitis hypoleucos as visitor management indicator species

Abb. 6: Calamagrostis pseudophragmites und Actitis hypoleucos als Indikatorarten in der Besucherlenkung

LITERATURE

Jungwirth M. et al., 1996: Die steirische Enns; Fischfauna und Gewässermorphologie. Univ. f. Bodenkultur, Abt. Hydrobiologie, Fischereiwirtschaft und Aquakultur. Wien.

Kammerer H., 2003.: Vegetationsökologische Studie Schotterbänke Gesäuse. Unpubl. Studie, Nationalpark Gesäuse GmbH. Weng.

Zauner G., 1999: Einfluß des Kormorans auf die fischökologischen Verhältnisse der steirischen Enns zwischen Liezen und Johnsbach. Univ. f. Bodenkultur, Abt. Hydrobiologie, Fischereiwirtschaft und Aquakultur. Unpubl. Studie im Auftrag des Amtes der steiermärkischen Landesregierung, Rechtsabteilung 6, Naturschutz. Wien.

Zechner L, 2003: Bestandserhebung des Flussuferläufers im Nationalpark Gesäuse 2003. Unpubl. Studie, Nationalpark Gesäuse GmbH. Weng.

SUSTAINABLE DEVELOPMENT OF WATER MANAGEMENT IN SEMIARID REGIONS BY MEANS OF ARTIFICIAL GROUNDWATER RECHARGE AND HARVESTING

ENTWICKLUNG EINER NACHHALTIGEN WASSERNUTZUNG IN SEMIARIDEN GEBIETEN DURCH DIE KÜNSTLICHE SPEISUNG VON GRUNDWASSER UND ABSCHÖPFUNG

Hans ZOJER

JOANNEUM RESEARCH Graz, Institute of Water Resources Management

ABSTRACT

The continuous water supply in semi-arid regions is a challenge. Irrigation of agricultural land and drinking water are permanently required, but the natural water supply follows a strong seasonal pattern. Water is abundant in winter, but scarce in the dry season. Techniques are sought that capture surplus water and store it at minimal losses until the time of demand. Among the available techniques, the artifical recharge of groundwater bodies is most appropriate. Several examples are presented, where specific site conditions require individual solutions.

Keywords: artificial recharge, groundwater, irrigation, drinking water, semi-arid region

ZUSAMMENFASSUNG

Die kontinuierliche Wasserversorgung in semi-ariden Gebieten ist eine Herausforderung. Wasser wird permanent für die Bewässerung von landwirtschaftlichen Flächen und als Trinkwasser benötigt, aber das natürliche Wasserangebot folgt saisonalen Schwankungen. Wasser ist im Winter ausreichend vorhanden, aber in der Trockenzeit gibt es Mangel. Es werden Techniken gesucht, durch welche das Überschusswasser gesammelt und bis zur Zeit des Bedarfes bei minimalen Verlusten gespeichert werden kann. Unter den möglichen Maßnahmen ist die künstliche Speisung des Grundwasserkörpers am besten geeignet. Anhand mehrerer Beispiele wird dargestellt, wie für Standortsbesonderheiten individuelle Lösungen gefunden wurden.

Schlüsselworte: künstliche Speisung, Grundwasser, Bewässerung, Trinkwasser, semi-arides Gebiet

INTRODUCTION

The contact of rock and water leads to dissolution processes of a great variance. Properties of the solid matrix (rock) are transferred to the liquid phase (water). While in carbonate rocks these processes are affected by the supply of carbon dioxide, in crystalline rocks other parameters play an important part. Saturation indices with respect to different mineral phases indicate the level of groundwater evolution in the individual hydrogeological units. On the other hand environmental isotope techniques render valuable information on the sources, movement and quantity of water in different environments. The combination of both technologies provides the most successful methodological improvement in delimiting recharge areas as well as in calculating groundwater storage capacity, which is essential for the wise utilisation of water resources.

Several methodological aspects are directed to the application of environmental and artificial tracers in combination with other, which allow a more accurate quantification of water resources and their particular components:

- Hydrochemistry: calibration of infiltration conditions by calculation of the calcite saturation index and the CO_2-balance, determination of the freshwater/saltwater interface and its seasonal change, continuous measurement of selected parameters for model development
- Environmental isotopes: determination of recharge areas, calculation of aquifer storage capacities by means of transport models, carbon fractionation in the root zone for understanding recharge mechanisms, determination of turnover time of karst water as an indication for disposing artificial recharge
- Artificial tracers: Determination of conduit flow in karst systems, evidence of vertical and horizontal flow in boreholes for the calculation of mixing processes
- Modelling of natural aquifer recharge, artificial recharge and sea water intrusion
- Remote sensing and implementation of geographical information systems

CURRENT SOLUTIONS AND LIMITATIONS FOR CARBONATE AQUIFERS

Inland aquifers

Due to the geological and climatic features, karst aquifers are characterised by large springs with sometimes enormous discharge fluctuations during the year (maximum in winter, minimum in summer and autumn). Many karst aquifers are overexploited because the maximum water demand occurs in summer time. High aquifer discharge in winter causes a considerable water surplus, which is not fully utilized because of the low water demand in this season. This situation creates a discrepancy between karst water availability and demand which sets practical limitations to karst water exploitation and use.

An example is given in the Zagros mountains, Western Iran near the Iraqian border, south of the town Pol e Zahab. Highly karstified rocks of the Asmari formation are intercalated with marls of the Fars and Ilam geological unit. Large karstic springs are located at the contact of these geological sequences. A sketch map is given in fig. 1. The spring Saab Garm is under investigation for re-pumping of spring water during winter time back into the karst aquifer in order to increase the spring discharge in the dry season.

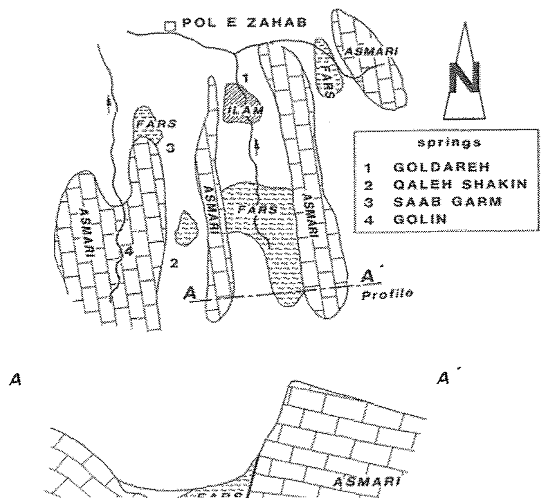


Fig. 1: Sketch map of karst springs in a location of Western Zagros mountains, Iran
Abb. 1: Karstquellen an einem Standort des westlichen Zagrosgebirges, Iran.

Coastal aquifers

According to the seasonal changes of salinity, coastal carbonate aquifers can be only utilised when the static pressure of the fresh water component is high and the freshwater/seawater interface in the aquifer is forced towards the sea. Overexploitation results in an increasing migration of sea water especially during the dry period. Different attempts to retain freshwater by means of boreholes and other technical constructions that prevent mixing with sea water in most cases failed. This shows clearly the actual limitations in the usage of these water resources. The reason for this natural conditions is based on changes of the sea water level since the Pleistocene (Fig. 2).

During glacial time the sea water level dropped because much of the fresh water in Europe was bound in ice. The base level of karstification dropped and reached the absolute drainage base, the sea. By melting of glaciers at the continent, the sea water level rose, but the karstification level still remains in a deep position. The consequence is the existence of submarine springs.

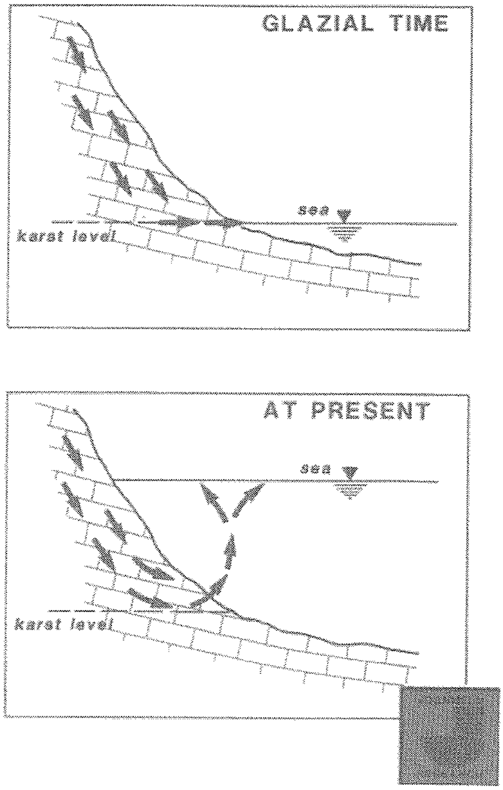


Figure 2: Karst level during the glacial time and presence,
Abbildung 2: Niveau des Karsten während der Eiszeit und in der Gegenwart

OPTIONS FOR ARTIFICIAL RECHARGE

A sophisticated water resources management in semiarid areas requires that surface and groundwater are artificially recharged. This ensures the continuous provision of water according to the demand despite temporal differences in the availability of ground water. Surface water storage in open reservoirs is limited by geological features and a high water loss due to evaporation. Artificial recharge depends on boundary conditions that are imposed by geology and hydrogeology.

Two systems are distinguished:

a) Autochthonous recharge: Recharge feeds water back into the same storage system; a part of the surplus water from the rain season is pumped back into the recharge area, taking into account the turnover time of subterranean water in the natural aquifer

   Water resource management requires:

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 38-44
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

- Identification of recharge mechanism and underground water storage, turnover time of fresh and brackish water bodies from coastal aquifers.
- Study of physical processes in the aquifer, especially the effects of storm events with gradual modifications
- Determination of the freshwater/seawater interface and its seasonal fluctualtion (coastal aquifers)
- Determination of potential sites for artificial recharge (point or areal infiltration), accounting for the turnover time of about half year for the distance from the discharge of the system (e.g. springs)

An example is given in fig. 1.

b) Allochthonous recharge: Recharge into a separate system; surplus water is transported to an aquifer with a sufficient storage capacity and without connection to the sea

Water resource management requires:

- Identification of recharge mechanism and underground storage, turnover time of fresh and brackish water components from coastal aquifers respectively for both aquifer systems
- Study of physical processes in the aquifer, especially the effects of storm events with gradual modifications for both aquifer systems
- Modelling of groundwater dynamics of the allochthonous aquifer in order to understand infiltration processes
- Selection of appropriate techniques for infiltration (punctual at the surface, punctual through injection boreholes, linear by infiltration drainages, areal by infiltration ponds)

The situation at a sub-marine spring near the village Kiveri at the Eastern coast of Peloponnesus peninsula is peculiar (fig. 3). The spring emerges approximately 8 m below sea water level next to a steep cliff of coastal limestones. It has been captured unsuccessfully by a dam in the shape of a half-circle. The seasonal fluctuation of chloride concentrations has not changes due to the construction of the dam. This indicates that mixing of seawater and fresh water bodies occur not directly in the contact zone of the rock with the sea, but rather within the karst aquifer.

During winter the springwater has the chemical quality of freshwater, but in summer it is brakish and unsuitable both for drinking and for irrigation. The proposed solution is to construct a pipeline to the valley behind the first mountain range. The vally contains several ponds for sedimentation of suspended material in order to recharge the Quaternary aquifer during the winter. The valley is open to the sea but near to the shore a conglomerate barrier prevents a quick outflow of groundwater to the sea.

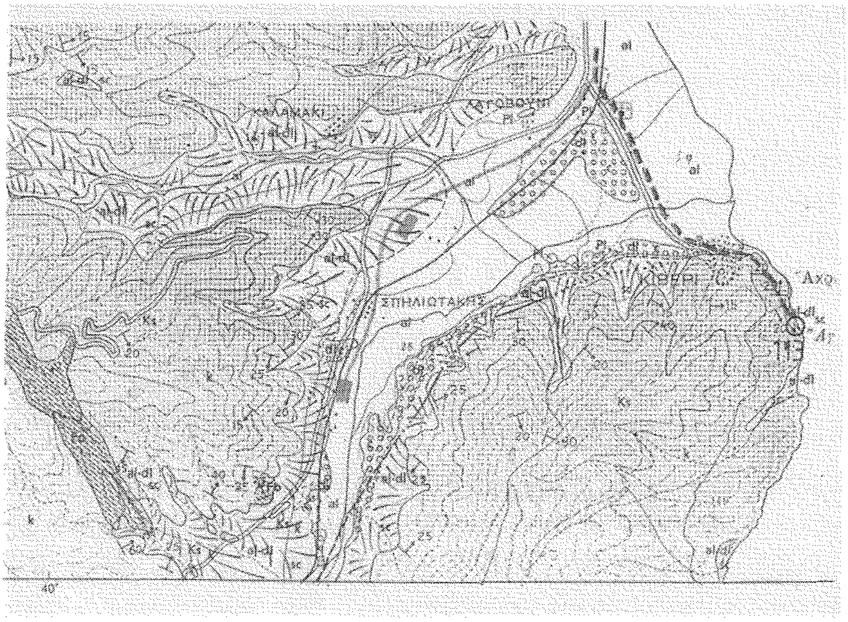


Fig. 3: Location map of the submarine spring (right corner near the village Kiveri) and the planned pipeline to Spiliotakis valley

Abb. 3: Stelle der unter dem Meeresspiegel liegende Quelle (rechte Ecke nahe der Ortschaft Kiveri) und die geplante Piüeline in das Spiliotakistal.

Another project applying artificial groundwater recharge will optimise the water supply of Teheran, Iran. The capital of Iran is located at the foothhills of the Elburs mountains (fig. 4). The southern flanks of this mountain range are very steep, not inhabitated, and covered by a scarce vegetation. The bedrock is dominated by schists and gneisses. Runoff is mostly surface flow during the whole season. However, many small streams flow from the mountain range to the South and seep down in the Quaternary Teheran aquifer. It is planned to catch selected streams west of Teheran and to recharge the aquifer artificially. After a certain residence time of the water belowground, it will be extracted by well galeries. Water treatment drinking purposes will be unnecessary, if the land-use within the protecte area is regulated by law.

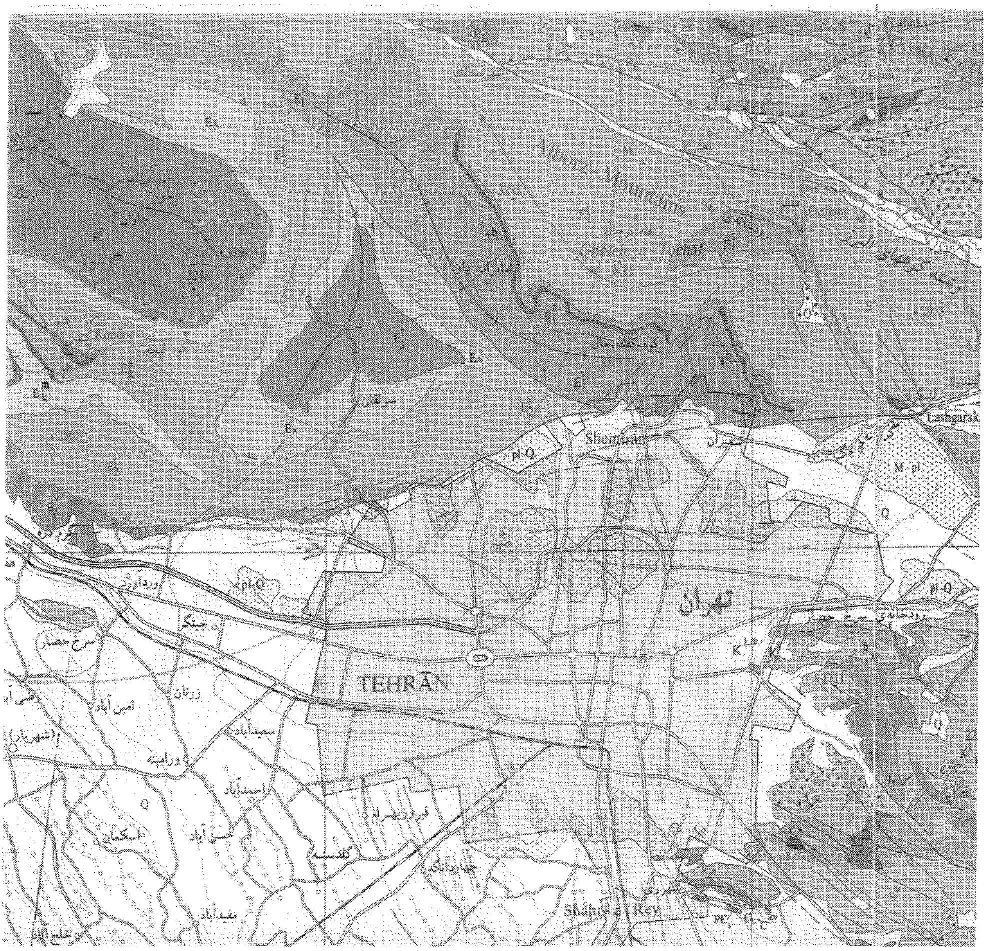


Fig. 4: Location map of Teheran and the adjacent part of Elburs mountains.
Abb. 4: Lage von Teheran und der angrenzend gelegende Teil des Elburs-Gebirges.

All the topics mentioned above are treated separately due to individual methods. There exists certainly a lack of combined application and synoptic view for better understanding of mass and solute transport processes. The continuous development of online sensors and data storage systems is recognized as an important challenge for present and future research activities. Standard sensors have to be improved to increase their accuracy and their resistance to extreme fluctuations in temperature and humidity under field conditions. Furthermore, the development of new sensors for selected dissolved solids is required.

SOIL WATER CONTENT MONITORING FOR IRRIGATION

MONITORING DES BODENWASSERGEHALTES FÜR DIE BEWÄSSERUNG

Peter Cepuder

Institute of Hydraulics and Rural Water Management, Department of Water, Atmosphere and Environment, Universität für Bodenkultur Wien (University of Natural Resources and Applied Life Sciences, Vienna), Muthgasse 18, A-1190 Vienna.

ABSTRACT

If irrigation is not well done, too much or too little water can stress plants. Controlling the soil water content in the whole root system may avoid water stress due to water deficiency and over-wetting may not appear. Also losses of nutrients by leaching can be avoided. During a two years period in an intensive used agricultural area in Austria (Marchfeld) monitored and managed subsurface drip irrigation was compared to standard sprinkler irrigation. In the course of planting onions the drip lines were installed in 7 cm depth. The soil water was monitored by FDR (frequency domain reflectrometry) soil water measurement device in 10, 20, 30 and 50 cm depth. The measurement interval was 30 minutes. Depending on the soil water content in different depths, the plant water requirement could be covered exactly by drip irrigation. Conventional irrigation was done on farmer's decision with the sprinkler system. The measurements in 30 and 50 cm depth should control deep percolation. Soil water monitoring led to optimum soil water content during the two vegetation periods, a 6 to 10 % higher yield was achieved and 20 to 28 % of irrigation water was saved. Another side effect was that the drip-irrigated plants were less affected by fungal infection, as the water application happened in the root zone.

ZUSAMMENFASSUNG

Eine schlecht durchgeführte Bewässerung verursacht im Falle einer Unter- als auch einer Überversorgung Pflanzenstress, was in weiterer Folge schlechtere Qualität als auch Mindererträge nach sich ziehen kann. Durch eine Kontrolle des Bodenwassergehaltes im Wurzelraum und einer gesteuerten Bewässerung kann dieser Wassermangel bzw. die Überversorgung mit Wasser vermieden werden. Durch diese Kontrolle kann auch ein Nährstoffverlust durch Auswaschung und dadurch eine mögliche Belastung eines Grundwasserkörpers verhindert werden. In einem zweijährigen Versuch in einer intensiv landwirtschaftlich genutzten Region in Österreich (Marchfeld) wurde eine Unterflurtropfbewässerung mit einer Standardberegnungsanlage verglichen. Die Tropfbewässerungsanlage wurde zeitgleich mit dem Anbau der Zwiebel in 7 cm Tiefe eingebaut. Der Bodenwassergehalt wurde mit einem Bodenfeuchtemeßgerät, welches auf der Basis von Frequency Domain Reflektometrie (FDR) arbeitet, in den Tiefen von 10, 20, 30 und 50 cm gemessen. Das Messintervall betrug 30 Minuten. In Abhängigkeit vom Wassergehalt in verschiedenen Bodentiefen konnte durch die Tropfbewässerung der Wasserbedarf der Pflanzen genau gedeckt werden. Die konventionelle Beregnung wurde nach den Anweisungen des Landwirtes (Praxis) durchgeführt. Durch die Messungen in 30 und 50 cm Tiefe wurde die Tiefenversickerung kontrolliert. Das Monitoring ermöglichte die Einstellung des optimalen Bodenwassergehalts während der Vegetationsperiode. Dadurch konnte der Ertrag um 6

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 45-52
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) *ISBN 3-900865-17-5*

bis 10% erhöht und im Gegenzug der Wasserbedarf um 20 bis 28 % gesenkt werden. Als weiterer positiver Effekt konnte ein deutlich geringerer Pilzbefall gegenüber den beregneten Flächen festgestellt werden.

INTRODUCTION

Water is essential for crop growth. Wrongly done irrigation can be stressful for crops. Too much as well as too little water can affect the growth in a negative way. Controlling the soil water content in the alterable root system can avoid water stress due to water deficiency. Over-wetting and a loss of nutrients by leaching can also be prevented. For drip irrigation the water application rate is one of the factors, which determine the soil moisture regime around the emitter (Brandt et al., 1971; Bresler, 1978). Root distribution and plant water uptake patterns can be influenced by controlled water application (Phene et al., 1991; Coelho and Or, 1996, 1999). Even for water application equal to the plant water need, part of the water may not be used by the plant and would most likely drain below the root zone. Therefore, controlled irrigation by soil water monitoring as close as possible to the plant water uptake rate may improve irrigation efficiency (Batchelor et al., 1996). Especially subsurface drip irrigation and online soil water monitoring systems can help to reach this goal.

MATERIALS AND METHODS

Nowadays conservation of groundwater is a basic concern in terms of environmental protection. This is particularly true for intensive used agricultural areas like the Marchfeld Plain. Careless use of water for irrigation events causes not only a lowering of the groundwater table but also leaching of nutrients into groundwater. Using drip irrigation systems can increase the efficiency of water applications. Furthermore, the availability of nutrients can be increased and leaching should be limited.

A field trial was carried out in the Marchfeld Plain, which is an intensive used agricultural area. The field was situated close to the experimental farm of the University of Natural Resources and Applied Life Sciences (BOKU), Gross-Enzersdorf, Austria ($48^0$10' N and $16^0$30' E). The area is 156 m above sea level and the terrain is almost flat. The dominant soil type in the area is Chernozem. According to USDA classification, soil was loamy silt or sandy loam down to 45 cm depth and sandy silt from 45 to 100 cm depth. The climate of the area is temperate, continental; cold winters with frequent rain; cool summers with occasional showers with an average annual precipitation of 510 mm and an average annual temperature of 10°C. The climatic diagram gives a short overview of the climatic situation (Fig. 1).

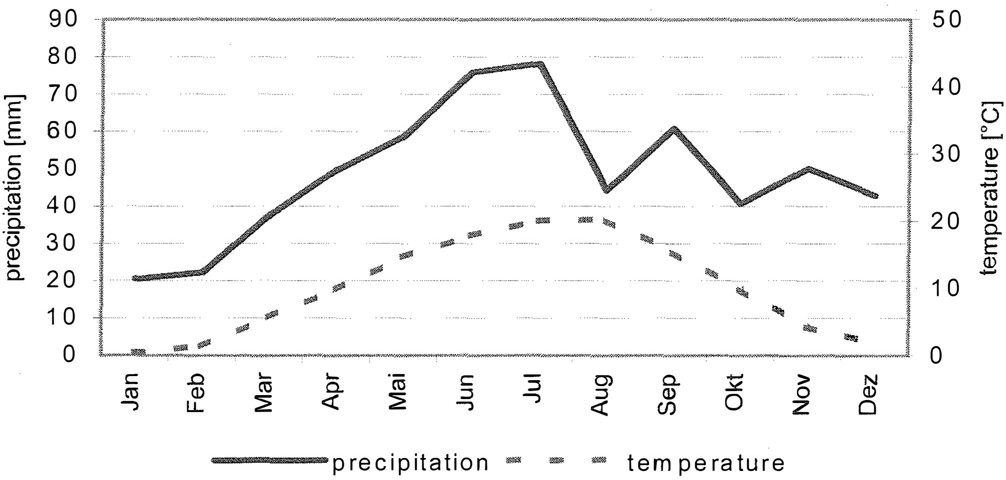


Fig. 1: Climatic diagram of Groß-Enzersdorf for the years 1990 to 1999.
Abb. 1: Klimadiagramm von Groß-Enzersdorf für die Jahre 1990-1999.

Over a period of two years a comparison between sprinkler and subsurface drip irrigation was done to measure the impact of these irrigation systems on yield, irrigation water, soil water content and costs. Sprinkler irrigation was managed on farmer's decision, and subsurface drip irrigation was monitored and managed by an online soil water-measuring device.

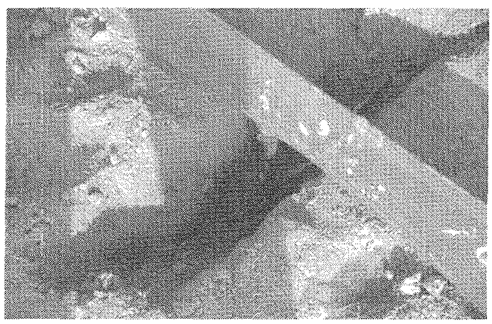


Fig. 2 Installation of drip irrigation system, planting of onions as a routine job and connection of drip lines with the main pipeline.
Abb. 2: Aufbau eines Tropf-Bewässerungssystems, die Pflanzung von Zwiebeln als Routinearbeit und die Verbindung des Systems mit der Haupt-Pipeline.

Onions were planted in beds; four times two by two rows. Planting of onions and installation of the drip tubes were done mechanically (Fig. 2). In one bed two drip lines were installed in a soil depth of about 7 cm. One drip line supplies four rows of onions. After the installation of the drip lines, the tubes were connected to the main pipeline with simple adapters (Fig. 2). The head station with filter and water meter was installed in the end. The pressure for the drip system was

0.8 bar. For the sprinkler irrigation, a standard solid-state system with spacing of 18 to 18 m was used. The nozzle diameter was 5 mm, the necessary pressure about 3.5 bar. Figure 3 shows the two irrigation systems.

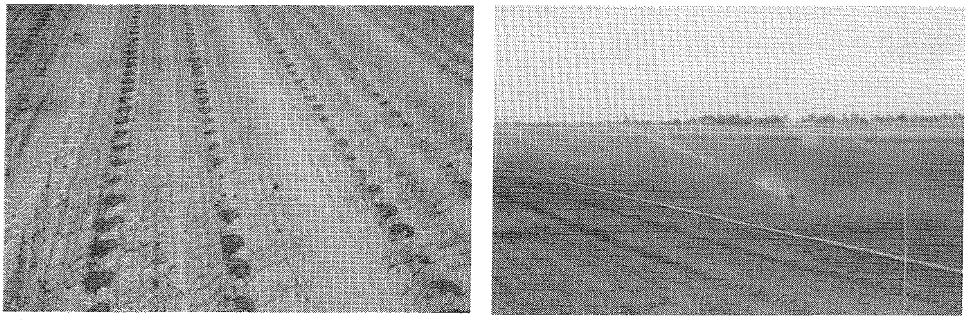
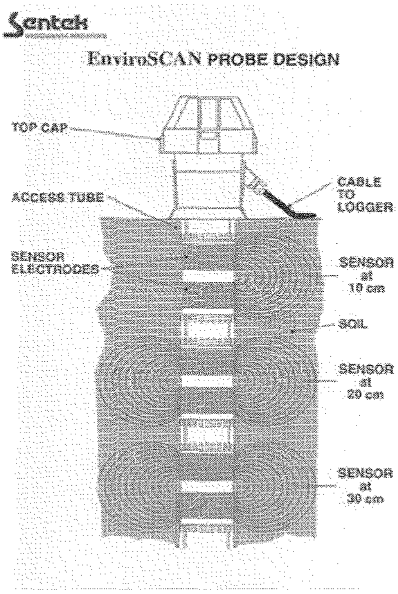


Fig. 3 Drip versus sprinkler irrigation. -- Abb. 3: Tropfbewässerung gegen Beregnung.

For irrigation management the soil water content was monitored by a soil water measurement device (FDR capacitance probe EnviroScan) in 10, 20, 30 and 50 cm depth. The measurement interval was 30 minutes. The EnviroScan probe (Fig. 4) consists of several sensors, which are located in an access tube in different depths and which measure the moisture of the soil. The data has to be read out every week or month depending on the data storage capacity. The measuring interval can be adapted from 1 to 999 minutes. The precision is specified with ± 1 % of the water content and the horizontal measuring radius is approximately 10 cm according to the company. One dielectric sensor consists of a pair of electrodes (circular metal rings) connected to an oscillator. The probe is inserted into a PVC access tube, which has to be installed in the field. When the probe is activated (using radio frequencies), the soil-water-air matrix around the PVC tube forms the dielectric of a capacitor, which then completes an oscillating circuit. Changes in soil water content cause a shift in frequency. For the capacitive method it is extremely critical to have good sensor-tube-soil contact for reliable estimation of soil moisture (Paltineanu and Starr, 1997, Campbell, 1990).



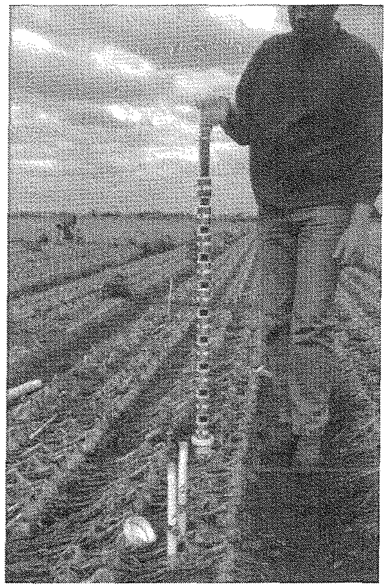


Fig. 4 Enviroscan (Sentek) and Sensors installed in field. – Abb. 4: Enviroscan (Sentek) und Fühler im Gelände.

RESULTS

Soil water content was measured every 30 min in the soil profiles of both irrigation systems. Figure 5 gives a comparison between the summed graphs from 0 to 35 cm depth. As noticeable from the graphs, irrigation was necessary between the end of June and the mid of August. Before (May) and after (mid of August) this period changes in soil water content clearly depend on rainfall and evaporation. During the irrigation period it can be seen that sprinkler irrigation was done with higher quantities than drip irrigation. Whereas sprinkler irrigation was done with amounts of about 25 to 40 mm and sub surface drip irrigation was done in amounts of 5 mm. Time intervals for sprinkler irrigation were about 10 days, if there was no rain. Sub surface drip irrigation was done depending on the soil water content in the root zone. Field capacity for 0 to 35 cm soil depth was 97 mm. A higher soil water content than field capacity means that there is a water movement downwards into deeper soil layers. This can indicate losses of water and nutrients. When the soil water content in 0 to 35 cm gets below 72 mm, the value for the "onset of stress" is reached, which indicates that drip irrigation has to be switched on (Fig. 5). As sprinkler irrigation was done at farmer's decision, irrigation started at a lower soil water content (60 mm). In this case onions got already some water stress.

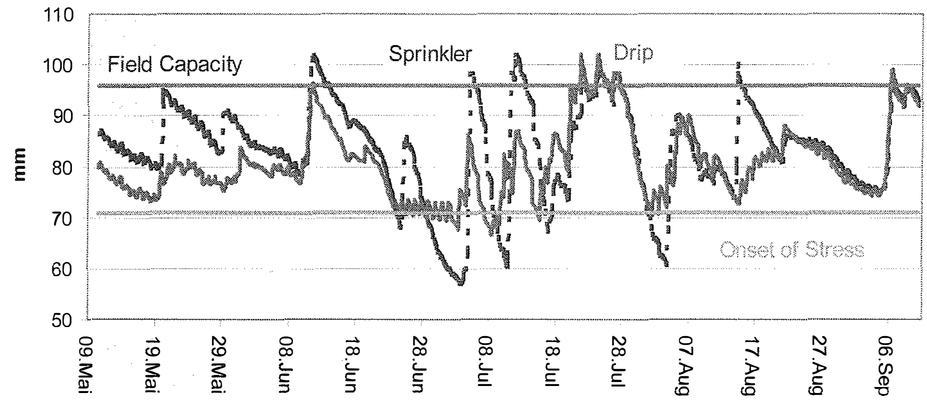


Fig. 5 Soil water content in the root zone (0 - 35 cm) of onions irrigated by sprinkler and sub surface drip.
Abb. 5: Wassergehalt in der Wurzelzone (0-35 cm) von Zwiebeln, die mit einer Unterflur-Tropfbewässerung und mit einer Beregnungsanlage bewässert werden.

If the soil water content is measured in 10 and 20 cm depth (main root zone for onions), plant water requirement can be exactly controlled with the help of sub surface drip irrigation. For both irrigation systems the measurements in 30 and 50 cm depth controlled deep percolation during the irrigation period from July 3rd to August 8th (Fig. 6).

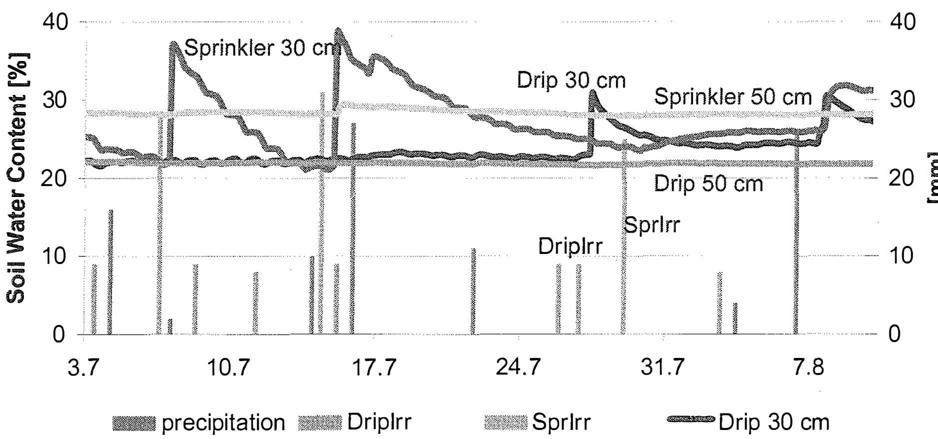


Fig. 6 Precipitation, drip- and sprinkler irrigation and soil water content in 30 and 50 cm of both irrigation systems
Abb. 6: Niederschlag und Wassergehalt im Boden in 30 und 50 cm Tiefe bei beiden Bewässerungssystemen.

There are losses of water out of the main root zone, which can be seen in Fig. 6. Water movement in deeper soil zones is noticeable in the case of the sprinkler irrigation on June 5th and

June 15th. This shows that irrigation by farmer's decision is not always efficient. The second irrigation on June 15th even led to a wetting down to 50 cm depth. On June 29th third irrigation with 25 mm was not recognized in 30 cm soil depth. On June 28th there is a peak in 30 cm depth of the sub surface drip irrigation that happened due to a broken valve. On August 6th rainfall of 26 mm resulted in an increase in soil water content in 30 cm depth of both systems.

A water meter was installed in the main pipeline after the electric pump and measured the water use. Rainfall in 2001 was just 200 mm during the vegetation period of onions; therefore irrigation by sprinkler was 283 mm and 226 mm for subsurface drip, respectively. As the rainfall was much higher in the year 2002 (411 mm), just 160 and 115 mm were necessary for irrigation. Sub surface drip irrigation saved water of 20 to 28% (Table 1).

Higher yield was obtained by subsurface drip irrigation. The yield was 72 t/ha for 2001 and 60 t/ha for 2002, which was 6% and 10% higher than for sprinkler irrigation. The size of onions was also more uniform in the drip irrigation area, which could result in more reasonable price (Table 2).

Tab. 1 Precipitation, irrigation and water saving during the two years of investigation.
Tab. 1: Niederschlag, Menge der Bewässerung und Wasserersparnis während der 2-jährigen Versuchsdauer.

Year	Rain	Drip	Sprinkler	Water saving
2001	200 mm	226 mm	283 mm	20 %
2002	411 mm	115 mm	160 mm	28 %

Tab. 2 Yields of sprinkler and drip irrigated fields
Tab. 2 Ertrag auf der Fläche mit Beregnung und mit Tropfbewässerung.

Year	Drip	Sprinkler	Difference
2001	72 t/ha	67 t/ha	6 %
2002	60 t/ha	55 t/ha	10 %

Subsurface drip irrigation is an effective, but also expensive irrigation method. In comparison to sprinkler irrigation, subsurface drip irrigation is not able to ensure profitable efficiency. The total annual costs of a subsurface drip irrigation system are about € 1800/ha, whereas the comparable costs of sprinkler irrigation are about € 500/ha. The difference between these costs has to be covered by a higher crop yield, which subsurface drip irrigation cannot guarantee. It is assumed that after a longer utilization of the dripper tubes the profit covers the additional costs of subsurface drip irrigation

Nevertheless, there is evidence that subsurface drip irrigation has positive effects on the quality and quantity of crop yield. Furthermore, plants irrigated by subsurface drip irrigation are less susceptible to crop diseases like downy mildew, which effects savings in the use of pesticides on the one hand and makes subsurface drip irrigation more lucrative for organic farming on the other hand. Organic farming products nowadays can reach a four times higher price.

CONCLUSIONS

The use of soil water monitoring systems such as the FDR-system in combination with subsurface drip irrigation results in an optimum water content in the root zone over the whole vegetation period. Furthermore, evaporation can be reduced to a minimum, which leads to water saving up to 28 %. Due to optimized soil water conditions an increase in crop yield up to 10 % can be achieved. In addition, crop diseases can also be reduced due to water application in the root zone. However, the benefit of subsurface drip irrigation does not cover the expenses.

Online measurement devices can reach ideal conditions of the soil water content for crop development. They are achieved when the water content is between "field capacity" and "onset of stress". Depending on the water content in the changing root system best water requirements can be delivered to the plants and soil conditions can therefore be more or less neglected.

REFERENCES:

Batchelor C., Lovell C., and Murata M., 1996: Simple microirrigation techniques for improving irrigation efficiency of vegetable gardens. Agric. Water Manage. 32:37-48

Brandt A., Bresler E., Diner N., Ben-Asher I., Heller J., and Goldberg D., 1971: Infiltration from a trickle source. I. Mathematical models. Soil Sci. Soc. Am. Proc. 35: 675-682.

Bresler E. 1978: Analysis of trickle irrigation with application to design problems. Irrig. Sci. 1: 3-17

Campbell J.E., 1990: Dielectric properties and influence of conductivity in soils at one to fifty Megahertz. Soil Sci. Soc. Am. J., Vol. 54.

Coelho E.F., and Or D. 1996: A parametric model for two-dimensional water uptake by corn roots under drip irrigation. Soil Sci. Soc. Am. J. 60: 1036-1049.

Coelho E.F., and Or D. 1999: Root distribution and water uptake patterns of corn under surface and subsurface drip irrigation. Plant Soil 206: 123-136.Paltineanu C.C., and Starr J.L., 1997: Real-time Soil Water Dynamics Using Multisensor Capacitance Probes: Laboratory Calibration. Soil Sci. Soc. Am. J., Vol. 61: 1576-1585.

Phene C.J., Davis K.R., Hutchmaker R.B., Bar-Yosef B., Meek D.W., and Misaki J., 1991: Effect of high frequency surface and subsurface drip irrigation on root distribution of sweet corn. Irrig. Sci. 12: 135-140.

FLOOD-INDUCED CHANGES IN SOCIO-ECONOMIC METABOLISM. A LOCAL CASE STUDY OF FLOOD IMPACTS ON SOCIETY

VERÄNDERUNGEN DES SOZIOÖKONOMISCHEN METABOLISMUS DURCH EIN HOCHWASSEREREIGNIS. EINE LOKALE FALLSTUDIE ÜBER DIE AUSWIRKUNG VON HOCHWASSER AUF DIE GESELLSCHAFT

Willi HAAS, Clemens M. GRÜNBÜHEL, Helmut HABERL

Institute of Social Ecology (Vienna), Faculty of Interdisciplinary Studies (Klagenfurt – Vienna – Graz), Klagenfurt University, Schottenfeldgasse 29, A-1070 Vienna, Austria

ZUSAMMENFASSUNG

Die Mehrheit der Studien über Folgen von Hochwasserereignissen behandeln lediglich den aufgetretenen monetären Schaden. Im Gegensatz dazu wird in diesem Beitrag das Konzept des sozioökonomischen Metabolismus herangezogen, um Schäden zu evaluieren. Anhand eines Fallbeispiels einer geschädigten Gemeinde durch das Hochwasser des Jahres 2002 quantifizieren die Autoren die Menge an zusätzlich entstandenen Material- und Energieflüssen. Eine weitere Fragestellung richtet sich nach der Reaktionsweise der Gemeinde auf das Extremereignis. Wurden aufgrund der Erfahrungen technologische Innovationen in den Wiederaufbau miteinbezogen, um zukünftige Material- und Energieflüsse zu senken? Die Berechnungen der Materialflüsse im Beispieldorf zeigen eine Zusatzbelastung von 6,7t/cap aufgrund des Hochwasserereignisses. Diese Menge beläuft sich auf etwa 40% der jährlichen Materialflüsse, die in einem Referenzdorf ohne Hochwasserereignis auftreten. Der zusätzliche Energiebedarf aufgrund des Hochwassers beläuft sich auf 11% des jährlichen pro-Kopf Konsums durch österreichische Haushalte. Technologische Innovationen sind im Wiederaufbau fast nicht zur Anwendung gekommen. Die Autoren folgern daraus, daß Maßnahmen eingesetzt werden sollten, die (a) die Bevölkerung besser informieren, (b) jenen Haushalten, die im Wiederaufbau auf Ökologisierung setzen, finanzielle Unterstützung dafür erhalten sollten und (c), daß Schadensbilanzen nach Hochwasserereignissen auch biophysische Daten enthalten sollten.

STICHWÖRTER: Hochwasser, sozioökonomischer Metabolismus, Material- und Energieflussanalyse (MEFA), Umweltauswirkungen

ABSTRACT

Flood impact assessments mostly focus on the quantification of damage costs. By contrast, this paper uses the concept of socio-economic metabolism to evaluate the impacts of floods. This paper presents a case study of impacts of a major flooding event in August 2002 on a small Austrian village. Our first research objective was to quantify additional material and energy flows. Our second research question was how the community reacted to the event. Has it implemented innovations to lower future material and energy flows, or has it essentially restored the status before the event? According to our calculations additional material flows in the study village caused by the flood amounted to 6.7 metric tonnes/cap. These flood-induced flows represent about 40% of the annual flows of a floodless reference settlement. The additional per-capita consumption of technical energy caused by the flood was 11% of the yearly Austrian average per capita household energy consumption. The implementation of innovations was minimal. The findings suggest better information policies, subsidies during restoring activities to improve the environmental performance in the long run and that damage balances should integrate monetary and biophysical damages.

KEYWORDS: Floods; socio-economic metabolism; material and energy flow accounting (MEFA); Environmental impacts

INTRODUCTION

Floods are natural events that can severely affect the functioning of societies. Infrastructure such as buildings and roads can be badly damaged which then, in turn, interrupt or at least hinder daily socio-economic activities of households and communities for months or even years. Instead of being able to conduct a normal life, restoration and repair activities have to be pursued.

Traditional assessments of flood impacts mostly focus on the quantification of damage costs, i.e. on monetary aspects of floods ("monetary damage balance"). By contrast, this paper uses the concept of socio-economic metabolism (Ayres and Simonis, 1994) to evaluate the impacts of floods on society and, in particular, on the functioning of biophysical processes ("biophysical damage balance"). The concept of social metabolism originated from the tradition of political economy and analyses the material and energy throughput of societies in a way that to some extent is analogous to the biological metabolism concept (Fischer-Kowalski et al., 1997). The throughput of materials and energy is vital for production and reproduction and hence for the quality of life. It is mediated by natural, social, economic, and technological processes. While the metabolism approach is routinely used in fields such as Industrial Ecology or Ecological Economics (Ayres and Ayres, 2002), its application to flood impact assessment is innovative. In this regard, the case study presented in this paper is to some extent exploratory.

The case study on a small Austrian village is located about 80 km from the country's capital Vienna in the lower Kamp valley. The research conducted assesses the impacts of a major flooding event in August 2002 that caused widespread damage across Europe. The village has about 700 inhabitants living in about 200 households. The results presented in this paper are based on an unpublished research report (Kromp-Kolb and Schwarzl, 2003).

RESEARCH QUESTIONS

An analysis of the impact of a singular event (e.g. a flood) on societal use of resources must distinguish three phases (Fig. 1): (1) "before," (2) "flood event and restoration," and (3) "after." Phase 1 "before" refers to the period before the flood event. An assessment of these characteristic flows under normal conditions is necessary for the interpretation of results referring to phases 2 and 3. Phase 2 "flood event and restoration" includes the occurance of the flood and the days following the event that are necessary to restore "normal" life, including "normal" socio-economic activities. During this phase, material and energetic flows can tremendously increase, decrease or even oscillate. This phase is chaotic and essentially unpredictable. Phase 3 "after" refers to the period after the event, when the community recovered and "normal" life continues.

Our first research objective had been the quantification and description of additional material and energy flows that emerged due to emergency measures, clearance, as well as repair works (phase 2). Our main interest was on the relation of these flows in comparison to the flows before the event took place (i.e. phase 1).

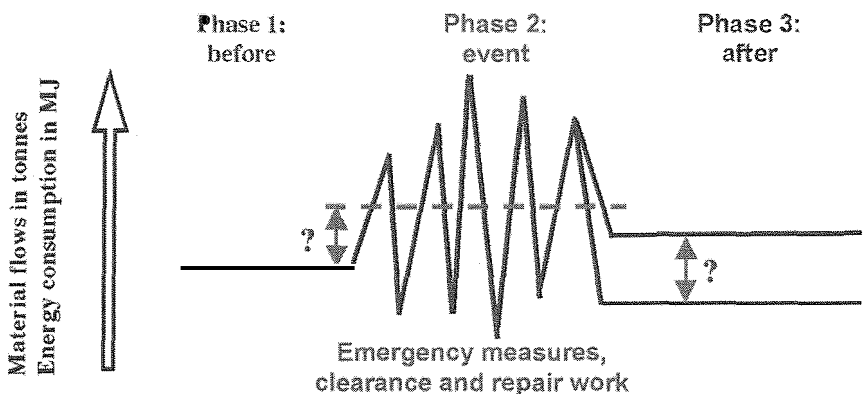


Fig. 1.: Schematic demonstration of floods' impact on social metabolism in three phases and research questions that emerge.

Abb. 1: Schema der Flutwirkung auf den sozialen Metabolismus in drei Phasen und daraus entstehende Fragen.

Our second research question was how the system, i.e. the community, reacted to the event. Has it renewed itself, eventually implementing innovations that would result in lower future material and energy flows (i.e. "constructive destruction;" (Schumpeter, 1934))? Has it essentially restored the status before the event, leaving the usual annual material and energy flows essentially unchanged; or has it even increased its material and energy throughput?

METHODS

Material and energy flow analysis (MEFA) has been established as a standard tool to quantify societal metabolism during the last three decades (Daniels and Moore, 2001; Daniels, 2002; Fischer-Kowalski, 1998; Fischer-Kowalski and Hüttler, 1999; Ayres et al., 1970). The methodological framework is well described in the literature. Examples include the *Handbook of Industrial Ecology* (Ayres and Ayres, 2002); a number of articles in the *Journal of Industrial Ecology* (e.g. Daniels and Moore, 2001, Haberl. 2001); and a methodological guide edited by the European Statistical Office (Eurostat, 2001). The approach applied in this study is the MEFA approach developed by IFF Social Ecology as described in the *Handbook of Physical Accounting* (Schandl et al., 2002; available online at http://www.iff.ac.at/socec). So far, the MEFA methodology has mostly been applied on the national level, but recently it has also been applied in a number of local case studies. Examples include Thailand (Grünbühel et al., 2003), the Nicobar Islands (Singh and Schandl 2003; Singh and Grünbühel 2003), as well as in a number of Austrian villages (Krausmann, 2003). MEFA methods will therefore not be described here in detail, but some key issues of local MEFA are discussed in the following paragraphs, in order to understand how the research proceeded.

Economic energy flows have long been a standard in statistical reporting. Energy flows of socioeconomic systems are analyzed at various levels of scale (e.g. by the International Energy Agency IEA). By contrast, material flow analysis (MFA) is a recent concept. Currently, international standards for MFA are being developed (Eurostat, 2001). Note, however, that significant modifications of conventional energy balances are necessary to establish energy flow accounts (EFA) that are compatible with MFA (Haberl, 2001). EFA and MFA are crucial tools for the description and analysis of the "bio-physical" structure of a socio-economic system. Quality of life, working hours, trade, transport, communication relations and consumption – all of these are issues that can be analyzed in the context of their relation to social metabolism.

Fig. 2 depicts the system boundaries applied in MEFA (MFA and EFA) and gives an overview of the main MEFA-derived parameters and headline indicators. Domestic Extraction (DE) encompasses all materials extracted from the domestic environment. Imports are inputs from other social systems. Domestic Processed Outputs (DPO) denotes the sum of all material outputs from socio-economic metabolism to the environment, i.e. to land, air, or water (including wastes and emissions), while exports are outputs to other social systems. To balance input and output, two items have to be considered: (1) changes in water content of materials flowing through the system and (2) oxygen needed for oxidation processes of incineration. However, the latter are not flows of primary interest and are counted separately (or outputs are counted without oxygen content, e.g. as C flows, not as CO_2). Direct material input (DMI) is defined as DE plus imports, the domestic material consumption (DMC) is defined as DMI minus exports.

A crucial issue in material flow analysis is the definition of system boundaries, i.e. the boundaries heuristically separating a social system from its natural environment and other social systems. In general, national MFAs are defined along international boundaries as they generally aim at compatibility with the system of national accounts (SNA) and can thus refer to economic definitions and conventions.

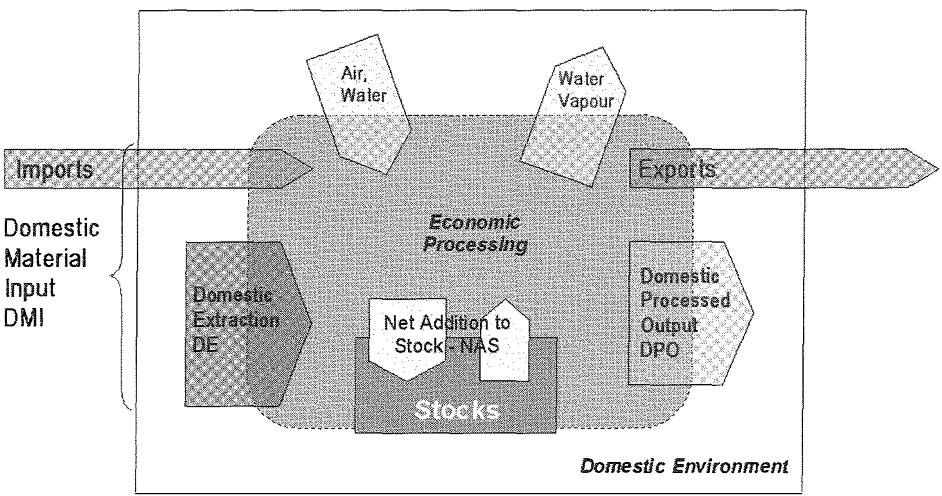


Fig. 2: Basic material flow analysis model (MFA model). Source: Slightly modified after (Matthews et al. 2000).
Abb. 2: Einfaches Materialflußmodell (MFA), Quelle: leicht verändert nach Matthews et al. (2000).

For material accounting purposes alone, principally any system would be suitable for analysis. If, however, physical properties are linked with social relations, the system must be coherent with regard to its reproductive logic and its characteristic dynamics. Only this coherence enables us to discuss the specific metabolic profile of social systems together with characteristic social and economic aspects. Thus, the bio-physical and social system boundaries are coherent with the concept of sustainable development and potentially contribute to its implementation. As the local population (local households) we regard all inhabitants who reside in the community for a period of longer than one year as a part of the system's human population.

In contrast to national-level MFA which is usually based on data provided by statistical offices, local-level MFA studies have only a very limited statistical data available. To generate biophysical data at the local level a research team collected primary data by conducting interviews with the members of the village's households, private enterprises, fire brigade, church, kindergarten and the municipal administration.

The people were interviewed face to face about quantitative data (e.g. square metre of damaged plaster, electricity bill) as well as narrative impressions and opinions on the flood's impact and the assistance after the floods. Enterprises, fire brigade, kindergarten and the municipal administration were interviewed comprehensivly. Hence, data from these sources could be aggregated to provide results for the private and public sectors. Regarding the private household sector, a subsample of all households was interviewed. Household data was extrapolated from the subsample of interviewed households (N=11) to the entire number of households existing in the community (N=200). The subsample represents 8% of the affected households and 20% of the monetary household damage in the village. Extrapolations were based on data for monetary damages of the interviewed households and the monetary damage of all of the village's households.

This study is the first application of MEFA for a biophysical damage balance. For reasons of limited resource availability, however, this balance could not be based on a comprehensive evaluation of all relevant flows. Empirical investigations had to focus on the quantification of flood-related flows, i.e. of flows during emergency measures, clearance and repair work (phase 2). In addition, all changes in activities and biophysical stocks (infrastructure, buildings, etc.) were recorded if they had the potential to influence flows in phase 3 in the long run (e.g. through upgraded insulation). In order to compare phase 3 data with phase 1 (see Fig. 3), material and energy flow data from a comparable case study and per capita data from Austrian statistics have been applied.

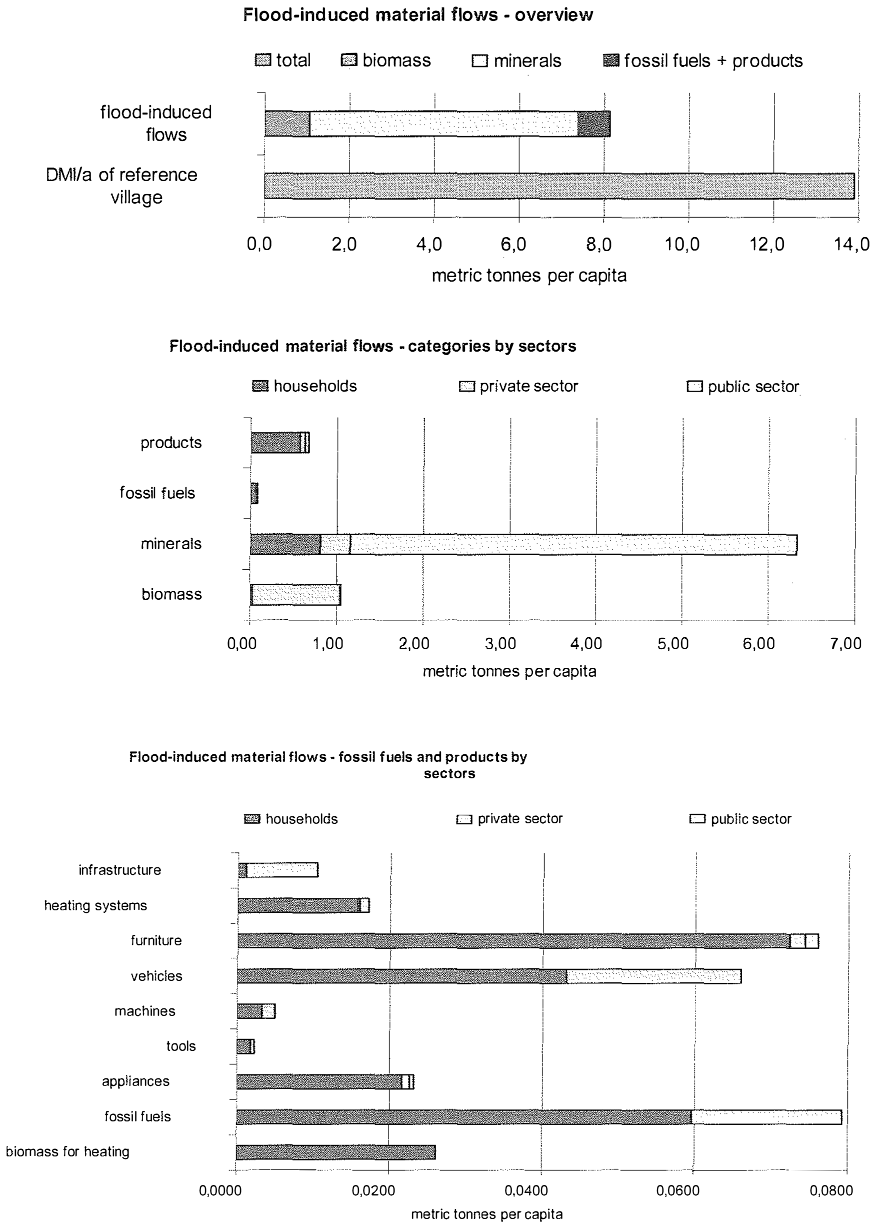


Fig. 3.: Additional material flows due to the flooding event. a) Comparison between flood-related flows and annual flows of a reference settlement, b) Material input by categories and broken down by sectors. c) Material inputs for less material-intensive products.

Abb. 3: Zusätzliche Materialflüsse durch die Flut: (a) Vergleich zwischen flutbezogenen Flüssen und den jährlichen Flüssen einer Referenzsiedlung, (b) Materialinput nach Kategorien und Sektoren, (c) Materialinput für wenig material-aufwendige Produkte.

RESULTS: FLOOD IMPACTS ON THE VILLAGE LEVEL

General description of flood impacts

The case study village is situated in the lower Kamp valley and has around 700 inhabitants. 140 of the approximately 200 households had been affected by flooding in the summer of 2002. The Kamp is a small river with a normal water flow of less than five cubic metres per second. The flow rate of the one-hundred-year-flood was estimated to be around 430 cubic metres per second (m^3/s) before the 2002 floods took place. The floods that caused the impacts analyzed here occured in two waves within a period of four days. The first wave had a flow of 800 m^3/s, the second reached 490 m^3/s. About two thirds of the village's area was inundated in the floods. The highest water level within the built-up area was 1.7 m. Damages included the breakdown of walls in houses, erosion of plaster of houses and streets, destruction or damage of furniture, mechanical equipment such as cars, trucks, electric equipment, boilers, or oil tanks. Oil spills spoiled cellars and walls. The monetary damage within the village amounted to about 7.5 million Euro (€). The largest share of this sum (€6.4 mio.) was recorded by households, €0.9 mio. by private enterprises and €0.2 mio. by the public sector.

Warnings of the approaching flood reached the inhabitants only 10 to 50 minutes before the inhabited area was flooded. Therefore, only few assets were rescued, obviously those that seemed to be most precious in this time of panic. Moreover, the warning was not very specific concerning the peak water level. Therefore, many of the last-minute rescue measures proved to be inadequate or even useless.

Flood-induced material and energy flows

According to our calculations based on the data collected in the interviews the floods caused about 6.7 metric tonnes/cap additional material flows in the study village. These flood-related flows represent about 40% of the annual flows in a floodless year of a nearby reference settlement with similar structural features (Fig. 3a). A disaggregation by sectors and material categories (Fig. 3b) shows the proportion of minerals: The reconstruction of plasters and streets required about 5t/cap of mineral materials. Biomass flows related to phase 2 amounted to 1 t/cap and were mainly caused by damages to stocks of a carpenter's warehouse located in the village. Products, such as cars, furniture and electrical equipment had to be replaced. Fossil fuels did not account for large amounts if represented in t/cap, however, their environmental impact was significant (see below). A breakdown by products reveals that repair work on streets and the surface of back yards accounted for more than 5.5 t/cap. A wide range of other products (see breakdown in Fig. 3c) amounted to about 0.3 t/cap.

The additional per capita consumption of technical energy was 5 GJ/cap for all sectors in the flood-affected village. This is about 11% of the average annual final energy consumption of private households in Austria (Fig. 4). The additional energy consumption was mainly caused by three factors: (1) *Rescue measures* needed heavy machinery to clear the area from trees, mud and damaged vehicles blocking access roads. Water needed to be pumped out of cellars. Military tanks and trucks assisted the local emergency services. Helicopters were needed to evacuate people from the rooftops of their inundated homes. (2) The *drying of houses* was a lengthy procedure; some houses were treated with drying equipment for an entire year. (3) The *repair works* of plasters and streets needed machinery and therefore energy.

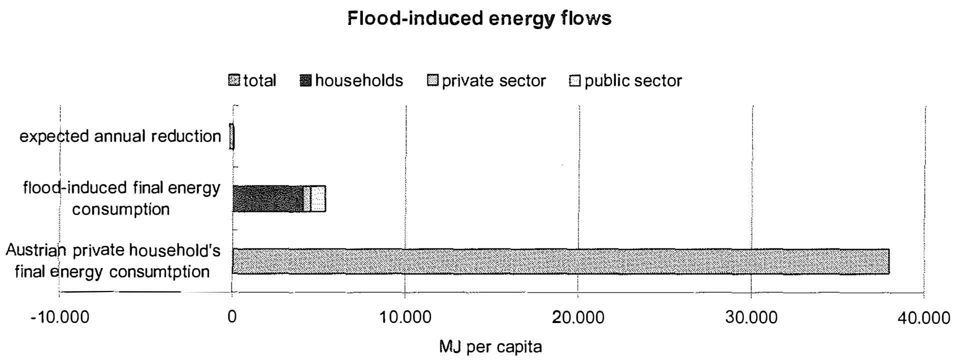


Fig. 4: The annual reduction expected in the village due to improvements in comparison with the energy consumption for emergency measures, clearance and repair work by sectors and the average annual final energy consumption of private households in Austria.

Abb. 4: Die erwartete jährliche Verringerung in der Ortschaft durch Verbesserungsmaßnahmen im Vergleich mit dem Energiebedarf für Notfallmaßnahmen, Aufräumungs- und Wiederherstellungsarbeiten nach Sektoren und der durchschnittliche jährliche Energieverbrauch eine privater Haushalte in Österreich.

Long-term impacts on energy flows

The second research question was whether the opportunity to replace equipment or refurbish houses with energy-saving technology was actually seized in order to decrease long-term energy consumption, and thus reduce pollution and CO_2 production in the long run. According to our data this effect seems to be negligible. Some of the changes implemented during reconstruction actually resulted in energy consumption increases, while others will lower future energy needs.

For example, one household installed a new central heating system instead of the old stoves, a substitution which is bound to increase average room temperature and thus energy consumption. Another building, however, was reconstructed with an upgraded insulation and will need less energy in future. The net effect, however, will probably be near zero (Fig. 4).

DISCUSSION AND RECOMMENDATIONS

The case village has not expected to be struck by a flood disaster of the kind that took place in the summer of 2002. All flood prevention measures were geared toward floods with less than half the amount of water flow than what actually occurred. Thus, the population, the village and district authorities, the fire brigade network and other emergency services were not prepared for such an event. Warning and evacuation were not timely and thus led to damage on movable goods. However, most of the damage occurred to immovables, such as paved surfaces and buildings. Hence, the significant impact on these structures that required a heavy investment of reconstruction materials and machines. Clearance of damaged materials and floodwater mud with heavy equipment added especially to the additional consumption of energy from fossil fuel. It is evident, therefore, that in addition to damage on high-value goods and personal belongings of the affected population the floods have had aa major impact on the community's physical structures and yearly resource consumption. The flows induced by the flooding event must be accounted for in addition to the regular yearly resource flows occuring due to socio-economic activities. The data shows, however, that it is possible to account for the additional flows and that a physical damage assesment depicts the physical extent of the impact on the society due to flooding.

The interviews with households showed that the population did not perceive a relation between global climate change and the occurrence of local extreme weather events (Kromp-Kolb and Schwarzl, 2003). Consequently, the reconstruction activities were not accompanied by measures that decrease resource consumption in the long run. The primary objective in reconstruction seemed to be setting up the original standard of living as quickly as possible, rather than regarding long-term effects. In a few cases, investments that would have occurred at a later date were advanced in time due to the damage. In addition to refraining from implementing innovative technology in reconstruction, the life-span of many goods was cut short and thus, additional resources mobilized due to the event. Ecological benefits due to the flood disaster cannot be observed.

Amounting to about 40% of the current annual material flows of a structurally similar, adjacent village, flood-related per capita flows of the analyzed village were significant. The additional per-capita consumption of technical energy caused by the flood was 11% of the Austrian average per capita household energy consumption. Flood-induced material and energy flows put additional burdens on the local as well as global ecosystems. The long-term reduction in material and energy flows caused by reconstruction and refurbishment activities was negligible. In light of the data presented above, we recommend three sets of measures in order to improve material and energy performance in the aftermath of flood distasters:

(1) Damage prevention and early warning. The short notice of warning led to avoidable losses and therefore unnecessary material and energy flows. Improved communication among public offices and information for the downstream population on water levels and flow rates could have increased the notice time to at least two hours. More risk-averse policies with respect to settlement patterns could have avoided some of the damages.

(2) Measures, such as awareness raising, disaster assistance, subsidies for reconstruction, etc. should be taken as an opportunity to improve the environmental performance of the infrastructure during reconstruction after flooding. The case study shows that there was no incentive for villagers to improve the environmental quality of their homes and infrastructure. If incentives were in place, floods (and other natural disasters) could open a window of opportunity for communal CO_2 reduction initiatives. The idea comprise using the financial aid of the public disaster funds for incentives to improving the eco-performance of new/reconstructed infrastructure.

(3) Flood events attract much public attention. Usually media coverage focuses on cases of personal misfortunes and financial losses. This media attention could, however, also be used as an opportunity to highlight biophysical losses and the additional pressures on the environment caused by society's reaction to such events. In addition, such events may be used to raise awareness for the necessity to counteract global process such as climate change, which are likely to increase the frequency of occurence of such events.

Biophysical damage balances should be established in parallel with monetary damage balances and the two should be presented in an integrated manner. Furthermore, the connection between environmental impacts, climate change and extreme weather events can be discussed to raise awareness for prevention measurements.

ACKNOWLEDGEMENTS

The research reported in this paper was carried out within the project "Flood-related changes in society's metabolism: a case study at local level" within the Austrian climate research program StartClim in 2003. We thank Birgitt Bodingbauer who conducted most of the interviews and helped in the data generation. Furthermore we want to thank the persons interviewed, the head of the village and the responsible municipality for their openness and assistance.

REFERENCES

Ayres R.U. and Ayres L.W., 2002: Handbook of Industrial Ecology. E. Elgar. Cheltenham, UK and Lyme, US.

Ayres R.U., Kneese A.V., and D'Arge R.C., 1970: Aspects of Environmental Economics. A Materials Balance - General Equilibrium Approach. John Hopkins University Press. Baltimore, MD.

Ayres R. U. and Simonis U. E.. 1994: Industrial Metabolism: Restructuring for Sustainable Development. United Nations University Press Tokyo, New York, Paris.

Daniels P.L., 2002: Approaches for Quantifying the Metabolism of Physical Economies. A Comparative Survey. Part II: Review of Individual Approaches. Journal of Industrial Ecology **6**(1): 65-88.

Daniels P.L. and Moore S., 2001: Approaches for Quantifying the Metabolism of Physical Economies, Part I: Methodological Overview. Journal of Industrial Ecology **5**(4), 69-93.

Eurostat, 2001: Economy-wide Material Flow Accounts and Derived Indicators. A methodological guide. Office for Official Publications of the European Communities. European Commission, Luxembourg.

Fischer-Kowalski M., 1998: Society's Metabolism. The Intellectual History of Material Flow Analysis, Part I, 1860-1970. Journal of Industrial Ecology **2**(1), 61-78.

Fischer-Kowalski M., Haberl H., Hüttler W., Payer H., Schandl H., Winiwarter V., and Zangerl-Weisz H., 1997: Gesellschaftlicher Stoffwechsel und Kolonisierung von Natur. Ein Versuch in Sozialer Ökologie. Gordon & Breach Fakultas. Amsterdam.

Fischer-Kowalski M. and Hüttler W., 1999: Society's Metabolism. The Intellectual History of Material Flow Analysis, Part II: 1970-1998. Journal of Industrial Ecology **2**(4), 107-137.

Grünbühel C.M., Haberl H., Schandl H., and Winiwarter V., 2003: Socio-economic Metabolism and Colonization of Natural Processes in SangSaeng Village: Material and Energy Flows, Land Use, and Cultural Change in Northeast Thailand. Human Ecology **31**(1), 53-87.

Haberl H., 2001: The Energetic Metabolism of Societies, P I: Accounting Concepts. J Industrial Ecology **5**, 11-33.

Krausmann F., 2003: The Transformation of European Land Use Systems During Industrial Modernization. A biophysical analysis of the development in Austrian villages since 1830. Regional Tendencies of the Interaction of Human Beings and Nature in the Process of the Transition from the Agrarian to Industrial Society. Tver: Ministry of Education of Russian Federation, 187-215.

Kromp-Kolb H. and Schwarzl I. (eds.), 2003: Startprojekt Klimaschutz: Erste Analyse extremer Wetterereignisse und ihrer Auswirkungen in Österreich. Institut für Meteorologie und Physik, BOKU. Wien.

Matthews E., Amann C., Fischer-Kowalski M., Bringezu S., Hüttler W., Kleijn R., Moriguchi Y., Ottke C., Rodenburg, E. Rogich D., Schandl H., Schütz H., van der Voet E., and Weisz H., 2000: The Weight of Nations: Material Outflows from Industrial Economies. World Resources Institute. Washington, D.C.

Schandl H., Grünbühel C.M., Haberl H., and Weisz H., 2002: Handbook of Physical Accounting. Measuring bio-physical dimensions of socio-ecomonic activities. MFA - EFA - HANPP. Federal Ministry of Agriculture and Forestry, Environment and Water Management, 75 p. Vienna.

Schumpeter J., 1934: Theorie der wirtschaftlichen Entwicklung. Eine Untersuchung über Unternehmergewinn, Kapital, Kredit, Zins und den Konjunturzyklus, Achte Auflage. Duncker & Humblot. Berlin.

Singh S.J. and Grünbühel C.M., 2003: Environmental Relations and Biophysical Transitions: The Case of Trinket Islands. Geografiska Annaler, Series B, Human Geography **85 B**(4), 187-204.

Singh S.J. and Schandl H., 2003: Socio-Economic Metabolism in the Nicobar Islands. Empirical Research in Society-Nature Interactions. Benzing B. and Herrmann B. (Eds.): Exploitation and Overexploitation in Societies Past and Present. IUAES-Intercongress 2001 Goettingen. LIT Publishing House, 169- Münster 184.

SUMMER-FLOOD 2002 IN SALZBURG/AUSTRIA- THE FLOODING OF THE MUNICIPALITY OF THALGAU

DIE HOCHWASSERKATASTROPHE 2002 IN SALZBURG- ÜBERSCHWEMMUNGEN IN DER MARKTGEMEINDE THALGAU

Michaela LEITGEB and Gernot FIEBIGER
WLV, Salzburg, Austria

ABSTRACT

In the summer 2002 heavy floods struck the City and Province of Salzburg/Austria. Extreme precipitations in the whole country led to high levels of runoff in the headwaters and to an increase in peak discharge in the torrents. As a consequence also the receiving rivers, such as the rivers Lammer, Saalach and Salzach grew in height and strength. In the City of Salzburg, the highest flood discharge of the river Salzach has been recorded (2.300 m^3/s!!) since 1899. Fortunately, the medieval downtown of Salzburg was not flooded. In the surroundings of the City of Salzburg heavy precipitations as well as enormous runoff led to floodings in housing areas of numerous communities. The Province was hit by debris flows, floods and landslides in the torrential catchments and headwaters. Three consecutive floods occurred in the northern district of Salzburg during the summer of 2002, on July 17, on August 7 and 12 respectively. An attempt is made to explain the disasters by the example of the floods in the municipality Thalgau with the catchment of the Fischbach-torrent. High-intensity precipitation as well as extreme runoff and discharge caused substantial damages to infrastructure and buildings, both inside and outside. Due to existing flood control structures larger damages and destruction could be avoided for the basin of Thalgau. After the disastrous floods the responsible agencies began immediately with the elaboration of a new concept for integrated flood control. The new control system has become necessary due to the high-intensity precipitation (145mm in 2 hours) beyond the design precipitation (80mm in 2 hours) of the existing torrent control system. The results are reported below.

KEYWORDS: Summer-flood Salzburg 2002; Disaster documentation, Integrated flood control

ZUSAMMENFASSUNG

Im Sommer 2002 war das Bundesland Salzburg/Österreich von schweren Hochwässern betroffen. Extreme Niederschläge im ganzen Land führten zu hohen Abflüssen in den Wildbacheinzugsgebieten und somit auch in deren Vorflutern, wie die Flüsse Lammer, Saalach und Salzach. In der Stadt Salzburg wurde der höchste Abfluss mit 2.300 m^3/s seit 103 Jahren gemessen. Bei einem Pegelstand der Salzach von 8,2 m war die Höchstmarke erreicht, glücklicherweise wurde die Salzburger Altstadt nicht überflutet. Im Bezirk Salzburg Umgebung führten diese starken Niederschläge sowie enormen Abflüsse zu Überschwemmungen von Siedlungsgebieten zahlreicher Gemeinden. Auch die Wildbacheinzugsgebiete im restlichen Teil des Landes Salzburg waren von Murenabgängen und Hochwässern betroffen. Die Gebietsbauleitung „Flach und Tennengau" war in diesem Sommer von drei aufeinanderfolgenden Hochwässern, am 17. Juli, am 7. August und am 12. August betroffen.

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 65-72
ÖGWEB (Österr Ges f Waldökoforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

Anhand der Hochwässer in der Gemeinde Thalgau und dem Einzugsgebiet des Fischbaches, wird der Ablauf der Ereignisse näher erläutert. Intensive Niederschläge sowie extreme hohe Abflüsse führten zu enormen Schäden an Gebäuden und Infrastruktur. Nach den Hochwässern wurde umgehend mit der Ausarbeitung eines neuen integralen Schutzkonzeptes begonnen. Die Ergebnisse werden hier vorgestellt.

STICHWÖRTER: Hochwasser Sommer 2002, Ereignisdokumentation, Integrales Schutzkonzept.

INTRODUCTION

The Province of Salzburg was struck by disastrous floods and debris flows during the summer 2002. In the mountains extreme precipitation led to a number of debris flows and floods during three events within four weeks on July 17 and on August 7 and 12 respectively. The main rivers in Salzburg, like the rivers Lammer, Saalach and Salzach, were overflown. At the same time, the riparian and settlement areas were largely inundated . In the communities of Kuchl and Golling the river Salzach flooded riparian housing areas causing substantial damages.

From a technical point of view the flood was an extraordinary disaster that was much larger than the calculated design flood of the master plans for flood control due to high soil moisture and the very high precipitation intensity on July 17 in the Fischbach in the municipality of Thalgau. That was the reason for the three consecutive flood events in the entire Thalgau valley. The basic idea of control, the levelling down of the flood peak discharge and its retention by temporary storage in flood basins was confirmed by 100-percent in the involved catchments. The existing control structures in the watersheds helped to avoid damages which could have resulted in losses of several millions of euros. In spite of the only partially implemented master plans in some catchments, damages occurred due to the extreme discharges. It was exactly determined by the analysis of the disasters that partially implemented master plans in catchments are able to prevent disastrous damages.

Also in the other districts of Salzburg with predominant torrents with debris flow potential the existing control concepts as well as the implemented master plans were confirmed. Also there larger damages could be avoided.

By the example of the flood disaster of Thalgau on July 17, the planned integrated watershed management will be discussed in detail.

THE THALGAU FLOODS

In summer 2002, on July 17, August 7 and 12, the Thalgau was struck by floods caused by alternation or interaction of runoff and discharge of three watersheds. The first event was

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 65-72
ÖGWEB (Österr Ges f Waldökoforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

caused exclusively by the high moisturisation of soils and extraordinary heavy precipitation in the northern catchment of the Fischbach bringing about large flooding and enormous damages in the lower course.

General conditions

Three torrential catchments drain to the village centre of Thalgau; the Fischbach-torrent, the Brunnbach-torrent and the river Fuschler Ache.

The northeast located Brunnbach has a catchment area of 18,9 km² and flows together with the Fischbach into the centre of the municipality of Thalgau.

The Fischbach catchment reaches 40,2 km² in southern direction and subdivides itself into several watersheds and flows approximately 1km after the centre of Thalgau into the river Fuschler-Ache. In the south the river Fuschler-Ache drains a catchment area of 97,6 km² in direction Thalgau.

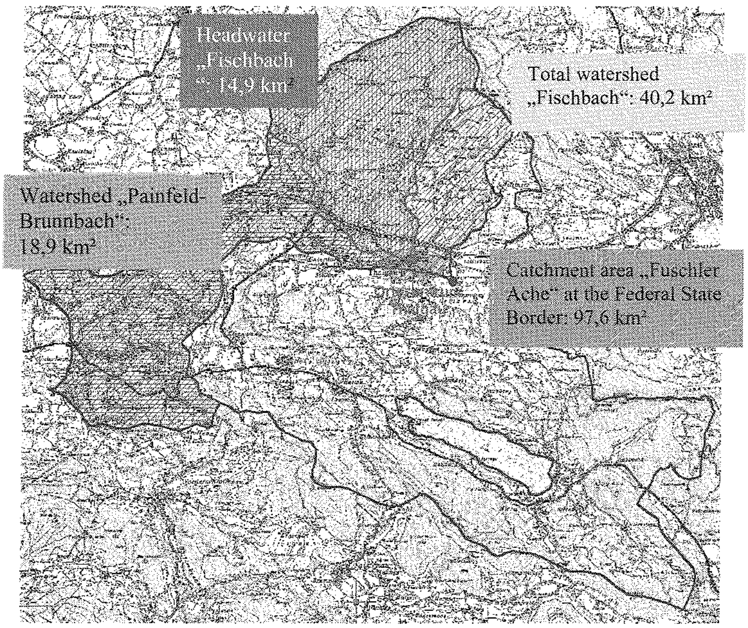


Fig. 1: Situation map: watersheds of the Plainfeld-Brunnbach and Fischbach-torrents and the river "Fuschler Ache" in the municipality of „Thalgau".
Abb. 1: Lagekarte: Einzugsgebiete des Plainfeld-Brunnbach, des Fischbach und der Fuschler Ache in der Gemeinde „Thalgau".

The area between approximately 500m and 1100m above sea level is situated geologically in the upper cretaceous layer and is characterized by the Traun-glacier of the Wuerm period. The bedrock consists of marl, clay stone and sandstone. The average annual precipitation amounts to 1750 mm.

NORTHERN PART OF THE CATCHMENT AREA OF "FISCHBACH"

In the northern part of the catchment area of "Fischbach" the headwater is characterised by three sub- catchments. In the forested headwater, the catchment is embossed by strongly branched spring ditches. The area is characterized by a swamp-like landscape. In the lower middle course, the "Fischbach" carves a canyon through the geological strata, where it meets "Waldbachgraben" creek.

Documentation of the event of 17 July 02

On July 17, 2002, heavy precipitation caused exorbitant amounts of runoff in the northern part of the Fischbach-catchment (14,9 km²) from the headwater and peak discharge in the channel and as a consequence the housing areas on the right and left bank of the Fischbach in the municipality of Thalgau were flooded (see Figure 5).

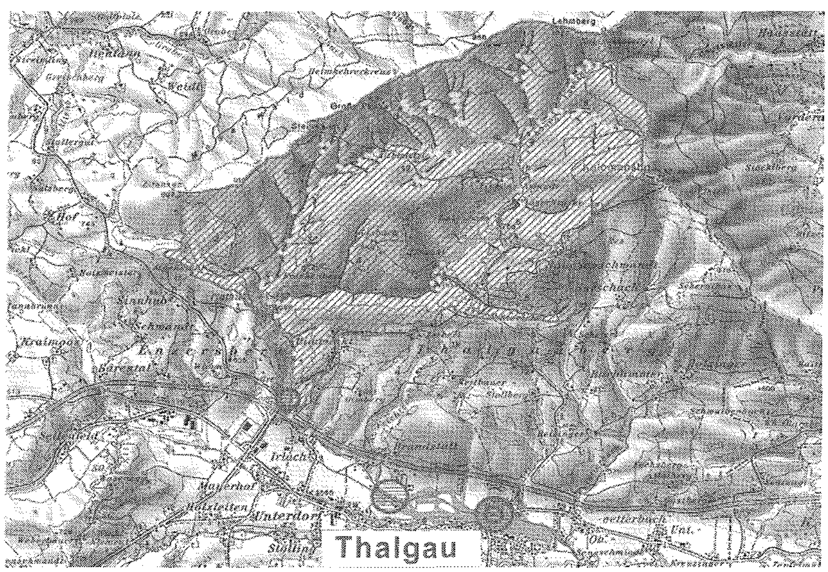


Fig. 2: Overview of the northern part of the Fischbach and flooded areas in the municipality of Thalgau (Hübl et al. 2003).

Abb. 2: Nördlicher Fischbach und überschwemmtes Gebiet in der Gemeinde Thalgau (Hübl et al. 2003).

High moisturisation of the catchment with 65mm precipitation within two weeks and a disastrous thunderstorm precipitation of 90 mm within 30 min led to peak runoff in the headwater and subsequent discharge in the channel amounting to 105m³/s. As a result, a high amount of erosional products and woody debris were mobilised in the tributaries of the Fischbach-torrent. Within 2 hours 1,5 million m³ discharge ran through the Fischbach-torrent. The processes in the Fischbach-torrent are to be distinguished at this disaster in debris flows from the small tributaries in the headwater and bedload transporting floods in the headwater and middle course as well as floods in the middle and lower courses.

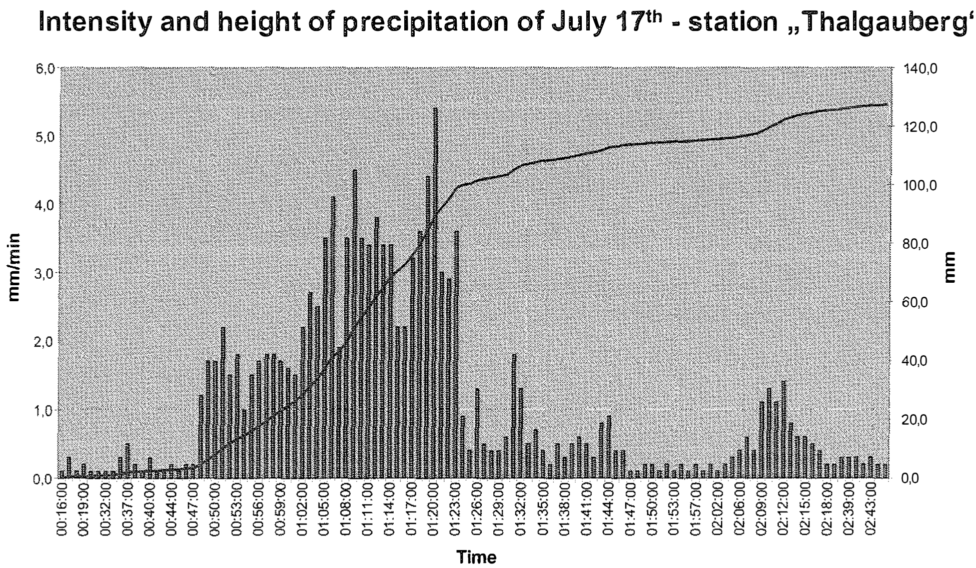


Fig. 3: Precipitation intensity diagramme ofthe disaster on July 17, 2002 at the Fischbach catchment.
Abb. 3: Niederschlagsintensitätsdiagramm des Ereignisses vom 17 Juli 2002 im Einzugsgebiet des Fischbach.

Existing control measures in the Fischbach-catchment.

The Fischbach is controlled by consolidation dams at the headwater/middle course areas. At the lower/middle course area exists a bedload dosing dam, a woody debris grid and finally a flood retention basin.

The control structures were working perfectly during the disaster. The triggered woody debris and bedload was held back by the structures. However, the control system could not cope with the enormouse water quantities as it was a too large disaster compared to the basic idea of control underlying design precipitation. This led to the overload of the downstream torrent channel and the flooding of the village of Thalgau.

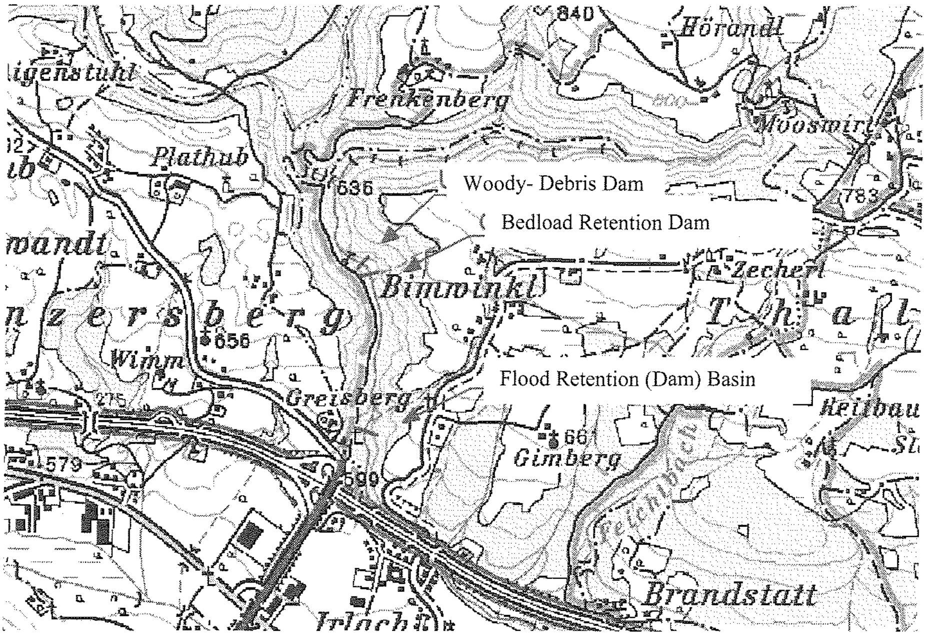


Fig. 4: Overview situation map of the existing control system in the Fischbach.
Abb. 4: Lageplan des existierenden Kontrollsystems am Fischbach.

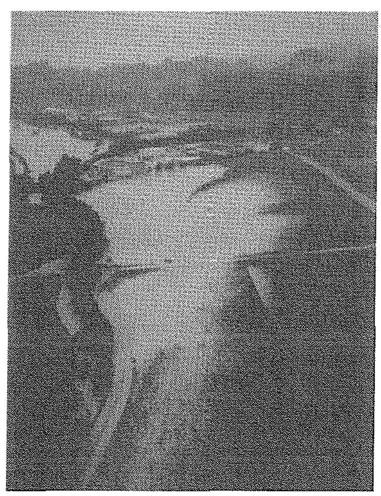


Fig. 5: Flooding of the western industrial area of Thalgau (12 August, 2002).

Abb. 5: Überflutung in der westlichen Industriezone von Thalgau (12 August, 2002).

INTEGRATED FLOOD – CONTROL FOR THE COMMUNITY OF THALGAU

The magnitude of the disaster events called for complementary measures in the single catchments. Responding to this challenge, the agencies started immediately to develop master plans for additional measures.

The results of the disaster documentation led to the following requests for the additional planning for a sustainable protection of the endangered development areas by integrated watershed management:

- Reduction of the peak-flood by temporary retention
- Bedload and woody debris management
- Protection of the breaching sites in direction to the dwelled areas

The construction of retention-structures, consolidation dams and bedload retention structures in the Brunnbach and Fischbach catchments and diversion dikes as well as flood trays in the lower course of the Fuschler Ache are to discharge the flood in a safe and controlled way.

Additional measures in the Fischbach headwater

In the Fischbach catchment wooden-crib dams should retain the bedload and debris in the headwater and middle course area. A retention basin in the Waldbachgraben with a capacity of 40.000 m^3 and a second flood retention basin in the headwater of the Fischbach with a storage capacity of 280.000 m^3 are to be implemented. In the case of floods the accruing water-quantities should be temporarily stored and gradually discharged to the lower course.
In the village of Thalgau along the Fuschler Ache lower course distanced dikes and flood trays should be implemented. The left bank will be technically protected and the natural floodplain on the right bank will be used for controlled flooding (flood- trays).

CONCLUSION

The flood disasters during the summer 2002 have shown clearly that the control measures of the Austrian Forest Engineering Service in Avalanche, Torrent and Erosion Control have functioned very well in the entire Federal Province of Salzburg, thus confirming the control systems . Given the fact, that the disaster of July 17, 2002 has been an extraordinary disaster in the Fischbach catchment, being far beyond the 100 year return period, the flood could not be discharged safely downstream.

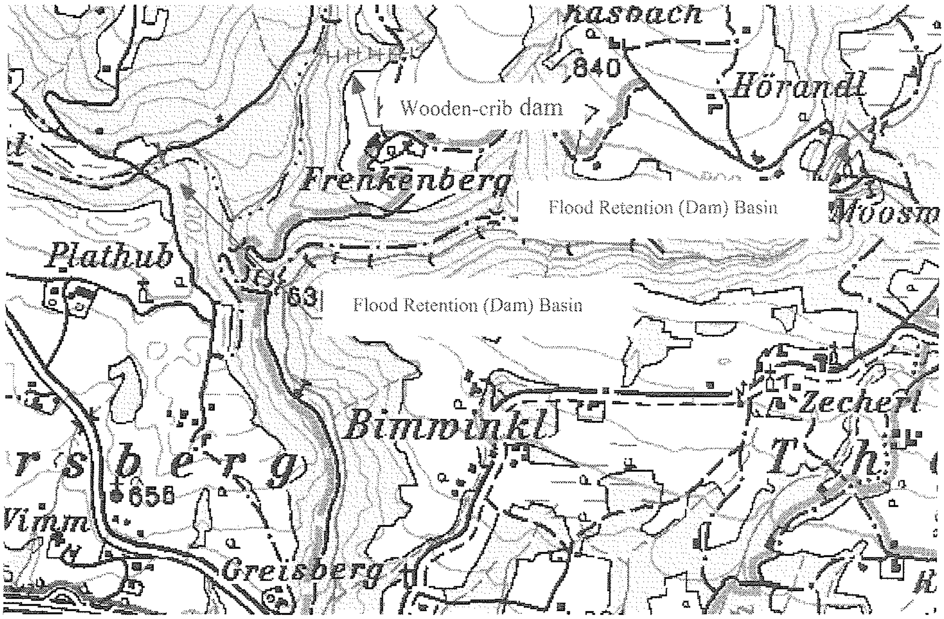


Fig. 6: Overview and location of existing control structures in the Fischbach and in the sub-catchment "Waldbachgraben".

The other floods were mainly in the reaches of the design-precipitation. In the systematically controlled watersheds disastrous damages were prevented. Floods and bedload disasters occurred only in partly controlled or uncontrolled catchments. The floods and disaster events of the summer 2002 have clearly shown that additional planning is necessary in the field of the natural disaster management. To guarantee sustainable protection of human life, infrastructure and settlement areas, further additional integrated watershed management activities are required, both in Salzburg and also all over Austria.

REFERENCES

Fiebiger G., et al., 2002: Report on 2002 floods in the Districts Salzburg & Hallein, Authority Salzburg of the Austrian Foresttechnical Service in Torrent, Avalanche and Erosion Control Engineering (unpublished),

Hübl J., et al., 2003: Documentation and analysis of the flood disaster of the July 17 2002 at the Fischbach, WLS report 87/volume 1, University of Natural Resources and Applied Life Science Vienna (in print)

Krimpelstätter L., 2003: Salzburg, annual report 2002 of the Austrian Forest-Technical Service in Torrent - and Avalanche Control, Federal Ministry of Agriculture and Forestry, Environment and Water Management, Vienna.

DER MÖGLICHE EINFLUSS VON GEÄNDERTEN UMWELTBEDINGUNGEN AUF DIE LAWINENAKTIVITÄT

POSSIBLE EFFECTS OF A CHANGING ENVIRONMENT ON AVALANCHE ACTIVITY

Peter HÖLLER

Bundesamt und Forschungszentrum für Wald, Institut für Lawinen- und Wildbachforschung, Hofburg – Rennweg 1, 6020 Innsbruck, Austria

ZUSAMMENFASSUNG

Lawinen werden zum überwiegenden Teil durch die Einflussfaktoren Topographie (Exposition, Neigung), Witterungsbedingungen (Klima) und Vegetation (insbesonders Waldflächen) gesteuert. Während die Topographie nicht vom Menschen beeinflusst werden kann, unterliegt das Klima und die Vegetation der menschlichen Einflussnahme. Es wird gezeigt, inwieweit Veränderungen dieser beiden Parameter auch Auswirkungen auf die Lawinenaktivität haben können. Aufgrund bisher durchgeführter Untersuchungen kann gesagt werden, dass es derzeit keine eindeutigen Anzeichen gibt, dass sich die Lawinenaktivität infolge Klimaänderung wesentlich verändert.

Auch bestehen derzeit keine Hinweise, dass neue (unbekannte) Lawinen aus bestockten Gebieten anbrechen und in den Siedlungsraum vordringen; Auswirkungen auf die Infrastruktur sind derzeit nicht zu erwarten.

STICHWÖRTER: Gebirgswald, Schneedecke, Schneegleiten, Lawinen, Klimaänderung

ABSTRACT

Avalanches are mainly governed by the three parameters topography, climate and vegetation (in particular forest cover). While topography cannot be influenced by humans, climate and vegetation may be affected by human influence. This paper shows how changes in the last two parameters may influence avalanche activity. Previous investigations show that there are no clear indicators that avalanche activity will change due to a changed climate. Currently there are no signs that new (and unknown) avalanches will release within forest sites and affect settled areas; effects on infrastructure seem to be unlikely at the moment.

KEYWORDS: mountain forest, snowpack, snow gliding, avalanches, climate change

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 73-82
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) *ISBN 3-900865-17-5*

DIE WIRKUNGEN VON SCHNEE AUF DIE UMWELT

Der Einfluss des Schnees auf die Umwelt ist mannigfaltig und kann sowohl positiv als auch negativ sein (Tab. 1). Eine ausführliche Beschreibung der in Tab. 1 genannten Wirkungen sowie der wechselseitigen Beziehungen zwischen Schnee und Vegetation findet sich unter anderem in Frey (1977).

Tab. 1: Auswirkungen von Schnee auf die Umwelt

Table 1: Effects of snow on the environment

Positive	Negative
Wasserspeicher (Trinkwasser)	Schäden an Pflanzen infolge Schneedruck, Schneelast und Kriechen der Schneedecke
Kein Eindringen von Frost in den Boden	Schneegleiten und daraus resultierende Erosion und Blaikenbildung
Pflanzenschutz (Schutz vor Frosttrocknis)	Lawinen
	Überschwemmungen (infolge plötzlicher Schneeschmelze)

Die angesprochenen negativen Effekte können aber in vielen Fällen nicht nur unmittelbare Schäden (primäre Effekte) verursachen (z.B. Bodenverletzungen, Schäden an Bäumen), sondern auch Auswirkungen auf den Siedlungsraum und die Infrastruktur haben (sekundäre Effekte).

Wie Tab. 2 zeigt, können diese Effekte von lokalem aber auch regionalem Charakter sein. Während Lawinen im Grunde nur lokale Wirkungen haben, sind die Auswirkungen von Überschwemmungen zumeist (über)regional.

Tab. 2 : Wirkung und Schadensausmaß von Lawinen im Vergleich zu Überschwemmungen

Table 2: Effects and amount of damage of avalanches compared to floods.

	Lawinen	Überschwemmungen
Betroffenes Gebiet:	Auswirkungen nahe beim Anbruchgebiet	Auswirkungen auch in großer Entfernung vom ursprünglichen Auslösepunkt
Zeitraum zwischen Eintritt und Wirkung:	kurz (unter einer Minute)	relativ lang (Stunden bis Tage)
Schadensausmaß:	mittel	hoch

Dabei werden Lawinen zum überwiegenden Teil durch die Einflussfaktoren Topographie (Exposition, Neigung), Witterungsbedingungen (Klima) und Vegetation (im besonderen Waldflächen) gesteuert.

Während die Topographie durch menschliche Tätigkeit nicht beeinflusst werden kann, unterliegen die beiden letzteren Parameter auch der menschlichen Einflussnahme.

Ziel dieser Arbeit war es einen kurzen Überblick über den derzeitigen Stand des Wissens bezüglich Auswirkungen veränderter klimatischer Bedingungen auf die Lawinenaktivität zu geben, sowie die maßgeblichen Wechselbeziehungen zwischen Wald und Schneedecke zu erörtern, um damit Rückschlüsse zu gewinnen, welche Wirkungen ein allfällig sich veränderter Waldzustand auf die Lawinenbildung hätte.

AUSWIRKUNGEN VERÄNDERTER KLIMATISCHER BEDINGUNGEN AUF DIE LAWINENAKTIVITÄT

Sichtet man die derzeit vorhandene Literatur, so erkennt man, dass sich nach aktuellem Wissensstand die zukünftige Lawinenaktivität (unter geänderten klimatischen Bedingungen) nicht deutlich verändern wird.

Föhn (1991) schreibt, dass weder die Schneedeckenqualität noch die Lawinenaktivität in den letzten 50 Jahren trendmäßige Änderungen aufweist. Zukünftig erhöhte Temperaturen während der Schneefälle und Setzungsperioden lassen aber vermuten, dass die abbauende Metamorphose und damit die Setzung und Verfestigung rascher vor sich gehen wird als bisher. Die Anzahl und Größe trockener, spontaner Hochwinterlawinen dürfte abnehmen, während die Bedeutung feuchter oder nasser Früh- und Spätwinterlawinen zunehmen dürfte.

Schneebeli et al. (1997) haben die Beziehung zwischen klimatischen Bedingungen und der Lawinenauslösung in den Jahren von 1947 bis 1993 untersucht und kommen zu dem Schluss, dass eine Modellierung der Lawinenaktivität aufgrund der sehr geringen Anzahl von extremen Ereignissen nicht erfolgreich durchgeführt werden kann. Wegen möglicher Lawinensituationen in Folge extremer Wetterbedingungen vermuten die Autoren aber, dass die klimatischen Ursachen für intensive Lawinenperioden während der letzten 100 Jahre stabil gewesen sind und keine Anzeichen einer Änderung in der näheren Zukunft vorliegen.

Martin et al. (2001) haben mit Hilfe eines Lawinengefahrenindex die aktuelle Lawinenaktivität und ihre Änderungen unter sich wandelnden klimatischen Bedingungen untersucht.

Sie folgern, dass die Lawinengefahr im Winter (vor allem im Februar) geringfügig und im Mai und Juni etwas deutlicher abnehmen wird, der relative Anteil an Nassschneelawinen aber zunehmen dürfte.

Laternser und Schneebeli (2002) analysierten eine 50-jährige Reihe der Lawinenaktivität von 84 schweizer Beobachtungsstellen und kommen zu dem Schluss, dass sie nicht in der Lage sind, eine langfristige Veränderung in der Lawinenaktivität festzustellen.

Diese Aufstellung zeigt, dass derzeit keine eindeutigen Hinweise vorliegen, dass sich die Lawinenaktivität infolge Klimaänderung wesentlich verändert.

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 73-82
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

AUSWIRKUNGEN EINES VERÄNDERTEN WALDZUSTANDES AUF DIE LAWINENAKTIVITÄT

Schnee und Wald

Den Einfluss des Waldes auf die Schneedecke und die Lawinenbildung haben unter anderem Gubler und Rychetnik (1991) sowie Frey und Salm (1991) untersucht. Die Wechselbeziehung zwischen Bäumen und Schneedecke aus Sicht der Schneemechanik hat Salm (1978) bearbeitet.

Veränderungen im Waldzustand können Auswirkungen auf den Aufbau der Schneedecke sowie auf allfällige Bewegungen in der Schneedecke (Schneegleiten) haben.

Die folgenden Beispiele sollen einige dieser Auswirkungen auf die Schneedecke (welche ja maßgeblichen Einfluss aufdie Lawinenbildung hat) verdeutlichen.

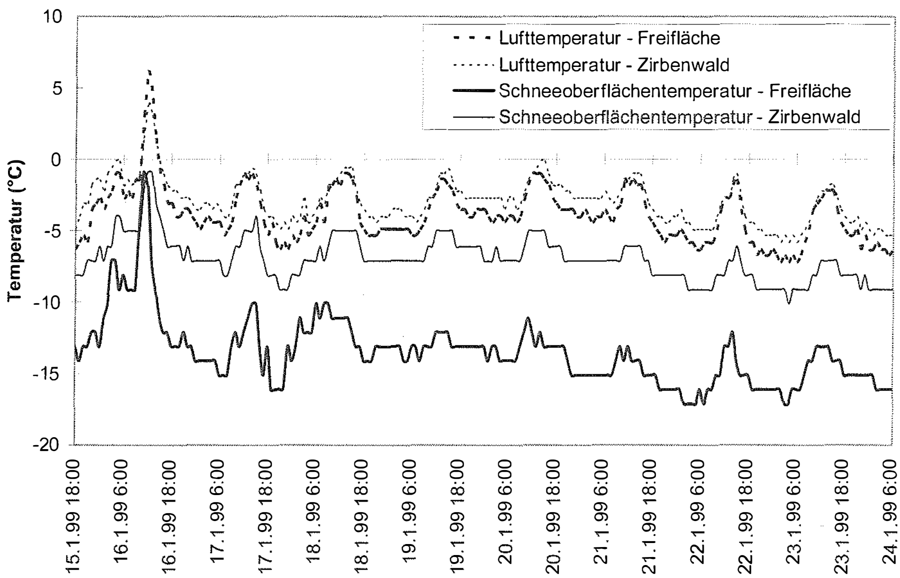


Abb. 1: Temperaturverhältnisse in einem Zirbenbestand und in einer angrenzenden freien Fläche (Lücke). Während die Lufttemperatur (gemessen 0, 1 m oberhalb der Schneedecke) an beiden Standorten recht ähnlich verläuft, ist die Schneeoberflächentemperatur im Bestand markant höher (Höller, 2001a)

Fig. 1: Air and snow surface temperature in a stone pine stand and a nearby opening. While air temperature (measured 0, 1 m above the snow surface) is very similar on both sites, snow surface temperature is significantly higher in the forest.

Zu den wesentlichen Vorteilen dichter Bestände zählen im Besonderen ein ausgeglichenes Waldinnenklima. So werden etwa reliefbedingte Gegensätze der Bodenoberflächentemperatur durch die Deckwirkung der Vegetation ausgeglichen (Aulitzky 1961).

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 73-82
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

Höller (2001a) hat Untersuchungen über den Einfluss des Waldes auf die Schneeoberflächentemperatur (T_s) durchgeführt; dazu hat er an charakteristischen Standorten im Bereich eines Zirben- und Lärchenwaldes nahe der Waldgrenze Messungen der Lufttemperatur in 2m und in 0,1m sowie von T_s durchgeführt; näheres über die Messmethodik findet sich in Höller (2001a). Dabei zeigte sich, dass die Schneeoberfächentemperaturen innerhalb der bestockten Fläche deutlich höher als auf der benachbarten Freifläche (Abb. 1); die Unterschiede zwischen Bestand und Freifläche können in sommergrünen Wäldern (Lärchen) zwischen 3 und 4,5°C, in immergrünen Wäldern (Zirben) sogar zwischen 3 und 7°C betragen (Abb. 1).

Maßgeblichen Einfluss auf die unterschiedlichen Schneeoberflächentemperaturen hat die Dichte des Kronendaches. Der Einfluss verschieden dichter Kronen auf die Strahlungsbilanz (und somit auf die Schneeoberflächentemperatur) ist in Tab. 3 dargestellt.

Tab. 3: Durchschnittliche Werte der Strahlungsbilanz im Hochwinter, dargestellt für eine Freifläche im Vergleich zu einem Lärchen- und Zirbenwald (Höller, 2001a)

Table 3: Net radiation (averaged values) in midwinter for an open slope compared to a larch and stone pine forest

	Freifläche	sommergrüne Bestockung (z. B. Lärche)	immergrüne Bestockung (z.B. Zirbe)
wolkenlose Nacht	- 65 W m^{-2}	- 35 W m^{-2}	- 25 W m^{-2}
bedeckte Nacht	~ 0 W m^{-2}	~ 0 W m^{-2}	~ 0 W m^{-2}

Während in klaren Nächten auf der Freifläche stark negative Strahlungsbilanzwerte vorliegen, sind die entsprechenden Werte innerhalb des Bestandes deutlich höher; je dichter das Kronendach desto höher die Werte der Strahlungsbilanz.

Die höheren Schneeoberflächentemperaturen im Wald tragen auch wesentlich dazu bei, dass hier die Ausbildung von Reifschichten in der Schneedecke kaum oder nur erschwert möglich ist.

Untersuchungen von Höller (1998) haben gezeigt, dass die Voraussetzungen zur Bildung von Oberflächenreif bereits bei Lücken ab einer Größe von 30 m^2 vorliegen können.

Daraus kann geschlossen werden, dass bereits relativ kleine Auflockerungen im Bestand zur Bildung von Reifschichten in der Schneedecke führen können, was auch Einfluss auf die Lawinenbildung haben kann.

Diese Zusammenhänge sind aber nicht nur bei der Bildung von Oberflächenreif von Relevanz, sondern haben ganz allgemein Bedeutung bei der Entstehung von Schwachschichten (insbesondere kantige Kornformen und Tiefenreif).

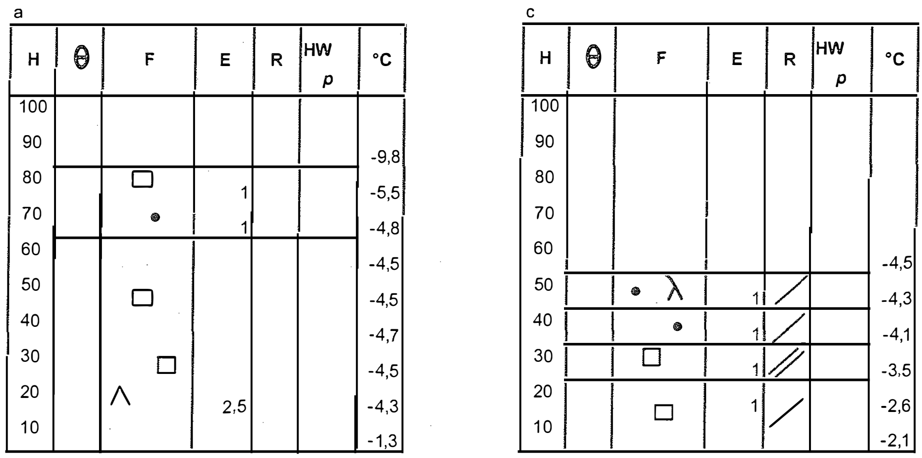


Abb. 2: Schneeprofile vom 20. Jän 1999; a...große Lücke, c...Zirbenwald
[H... Schneehöhe (cm), θ...Wassergehalt (%), F... Kornform (⋋..zerfallene Niederschlagsteilchen, ●...rundkörniger Altschnee, ○...Schmelzformen, □...kantige Formen, ∧...Tiefenreif), E...Korngröße (mm), R...Härte (/...gering, //...hoch); HW...Wasserwert].

Fig. 2 : Snow profiles from 20 Jan 1999; a...great clearing, c...stone pine forest
[H..snow depth (cm), θ..water content (%), F... grain shape (⋋..fragmented particles, ●...rounded grains, ○...wet grains, □...faceted grains, ∧...depth hoar), E...grain size (mm), R...hardness (/...low, /...high); HW...water equivalent].

Die Abb. 2 zeigt zwei Schneeprofile innerhalb und außerhalb eines Zirbenbestandes im Jänner 1999.

Man erkennt Tiefenreifschichten bzw. kantige Kornformen (an der Basis der Schneedecke) nicht nur in der Lücke, sondern auch innerhalb des Bestandes. Oberflächennahe kantige Kornformen (in den obersten 10 cm der Schneedecke) sind nur in der Lücke zu erkennen, nicht jedoch innerhalb des Bestandes.

Die aufbauende Metamorphose (Bildung von kantigen Kornformen und Tiefenreifschichten) erfordert einen Temperaturgradienten in der Schneedecke von mindestens 10°C/m (McClung und Schaerer, 1993). Ein Gradient dieser Größenordnung ist auf Freiflächen (insbesondere nach Kälteperioden und auf Schattseiten) sehr häufig vorzufinden, innerhalb bestockter Flächen nicht so leicht möglich (aufgrund höherer Schneeoberflächentemperaturen). Wenn die Schneehöhe im Wald jedoch gering ist, kann der Temperaturgradient trotz wärmerer Schneeoberfläche auch Werte von 10°C/m erreichen, sodass kantige Kornformen an der Basis der Schneedecke (Vorstufe zum Tiefenreif) nicht nur auf Freiflächen und Lücken sondern auch innerhalb bestockter Flächen möglich sind (Abb. 2).

Die Gradienten im Bereich der obersten 10 cm der Schneedecke können sowohl in Lücken als auch in Beständen sehr ausgeprägt sein (deutlich mehr als 10°C/m), dennoch konnten bisher nur in Lücken oberflächennahe Tiefenreifschichten gefunden werden, nicht aber innerhalb bestockter Flächen. Dies dürfte damit zusammenhängen, dass ausgeprägte Gradienten in den obersten Schichten der Schneedecke oft nur an wenigen Tage erhalten sind und zwar deshalb, weil die Gradienten hier sehr stark von T_s abhängig sind; die Schneeoberflächentemperatur erreicht aber nur während kalter und klarer Witterunsgperioden sehr tiefe Werte und diese Perioden sind zumeist nur von kurzer Dauer.

Es zeigt sich jedenfalls, dass eine allfällige Öffnung des Kronendaches markante Auswirkungen auf die darunterliegende Schneedecke, respektive auf den Schichtenaufbau, haben kann. Das heißt, bei der Bewirtschaftung von Gebirgs- und Schutzwäldern ist unbedingt auch darauf Rücksicht zu nehmen, dass das Kronendach weitgehend geschlossen bleibt.

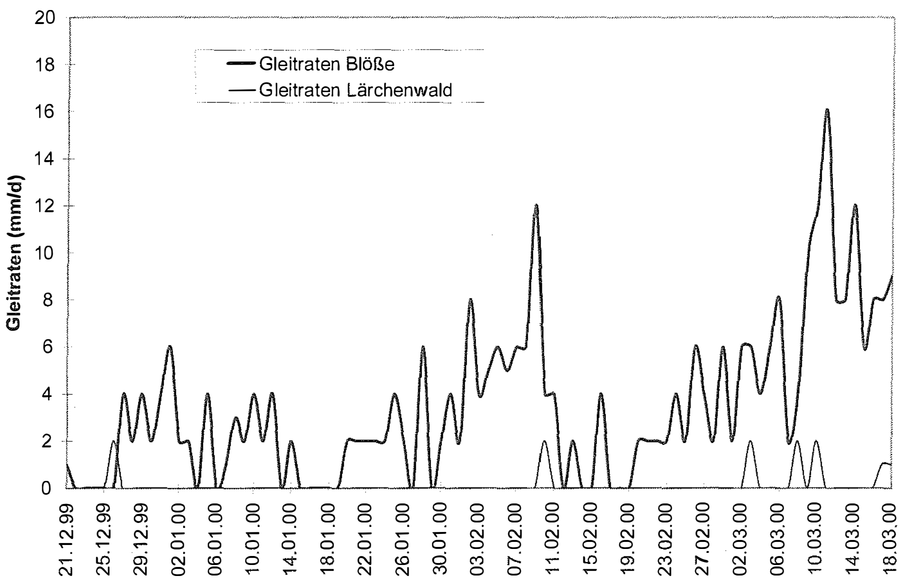


Abb. 3: Gleitraten in einem Lärchenwald und einer angrenzenden Blöße

Fig. 3: Glide rates in a larch stand and a nearby clearing

Aber nicht nur der Aufbau der Schneedecke sondern auch Bewegungen in der Schneedecke werden maßgeblich durch den auf dem jeweiligen Standort stockenden Bestand gesteuert. Untersuchungen von Höller (2001b) über das Schneegleiten in einem südexponierten inneralpinen Lärchenwald haben gezeigt, dass Gleitraten im Bestand zwar möglich sind, in der Regel aber so geringe Ausmaße annehmen, dass Gleitschutzbauten nicht erforderlich sind. Es ist aber ein deutliches Ansteigen der Bewegungen zu registrieren, sobald der Bestand Lücken und Blößen aufweist (Abb. 3). Auch Zenke (1985) hat darauf verwiesen, dass der Waldbestand Bestockungslücken aufweisen muss, damit sich die Schneedecke im Bergwald talwärts in Bewegung setzen kann.

Zu erwartende Auswirkungen auf die Lawinenbildung

Nach Gubler u. Salm (1992) ist eine ausgedehnte Schwachschicht notwendige Bedingung für die Bildung von Schneebrettlawinen.

Das heißt, dass bei Fehlen von Schwachschichten - sie bestehen nach aktuellen Untersuchungen von Föhn (1992) zu 80% aus Oberflächenreif, Tiefenreif oder kantigen Kristallformen - die notwendige Voraussetzung zur Lawinenbildung nicht gegeben ist.

Im vorigen Abschnitt wurde gezeigt, dass nur in dichten Beständen der Aufbau von Schwachschichten verhindert wird, dass aber bei Auflockerungen im Kronendach (oder beim Auftreten von Lücken und Blößen) sehr wohl Schwachschichten entstehen können. In Beständen mit einem ungenügenden Schlussgrad können daher die Voraussetzungen (nämlich das Vorhandensein von Schwachschichten in der Schneedecke) zur Lawinenbildung vorliegen.

Dass innerhalb derartiger Bestände in der Tat Schneebretter möglich sind, wurde unter anderem auch von Altenhofer (1996) dokumentiert. Die Beispiele zeigen Lawinenanrisse in einer kleinen Fichtenwaldlichtung (in der Nähe des Sonnkogels bei Leogang, Salzburg) sowie in einem lichten Lärchenbestand (in der Nähe des Frommerkogels bei Hüttau, Salzburg). Wenngleich es sich dabei um durch Schifahrer ausgelöste Lawinen handelte, so zeigt dies doch, dass das Risiko von Lawinen in bestockten Flächen nicht unterschätzt werden darf.

Aber nicht nur Schneebrettlawinen sondern auch Gleitschneelawinen sind in die Betrachtungen miteinzubeziehen. Diese Form der Lawine entsteht nicht durch einen Bruch der Schneedecke, sondern durch eine plötzliche Beschleunigung der gleitenden Schneedecke. Wie oben bereits ausgeführt, kann das Schneegleiten aber gerade in Lücken und Blößen südexponierter Lärchenbestände recht beachtliche Ausmaße annehmen.

Dass dadurch auch kleine Lawinen und Rutsche ausgelöst werden können, wurde von Höller (1997) in einem Lärchenbestand oberhalb von Neustift im Stubaital dokumentiert.
Ob die hier dargestellten Entwicklungen auch Auswirkungen auf Infrastrukur und den Siedlungsraum haben können, wurde von Höller (2002) abgeschätzt. Er hat die Zahlen der Forstinventur (Veränderung der Zahl der Lücken und Blößen) jenen der Lawinenstatistik (Veränderungen der Zahl der Lawinen die unterhalb der Waldgrenze abgebrochen sind) gegenübergestellt und gefunden, dass derzeit keine Hinweise bestehen, dass Lawinen aus bestockten Gebieten in den Talbereich vordringen können.
Zieht man jene Studien (BayForklim, 1999; UBA, 2004) heran, die eine Verschiebung der Vegetationsgrenzen nach oben erwarten, wären auch positive Auswirkungen möglich. Nach dem Abschlußbericht des Bayerischen Klimaforschungsprogramms (BayForklim, 1999) wird die Erwärmung zu einer Verschiebung der heutigen Obergrenze charakteristischer Waldgesellschaften um ca. 50 – 100 m nach oben führen. Das Umweltbundesamt (UBA, 2004) geht davon aus, dass eine Verschiebung der Vegetationszonen um bis 180 Höhenmeter nach oben möglich ist. Berücksichtigt man, dass etwa 30 % aller im Zeitraum von 1967/68 bis 1992/93 untersuchter Lawinen zwischen 1800 m und 2000 m ihren Ausgang nehmen (Luzian, 2002) - was in etwa der Höhe der Waldgrenze entspricht - so kann dieses prognostizierte Hinaufrücken des Waldes auch positive Wirkungen auf das Lawinengeschehen haben.

SCHLUSSFOLGERUNG

Der Gebirgswald spielt unbestritten eine maßgebliche Rolle um die Schneedecke zu stabilisieren und Schneebewegungen (Schneegleiten) zu minimieren.
Solange diese Bestände geschlossen (dichter Schlussgrad) und nicht von Lücken und Blößen unterbrochen sind, wird die Bildung von Schwachschichten in der Schneedecke weitgehend unterbunden und das Risiko von Lawinen stark minimiert. Dazu kann eine Waldbewirtschaftung beitragen, die insbesondere die Schutzwirkung im Auge hat.
Neue (bisher nicht bekannte) Lawinen, die aus bestockten Gebieten anbrechen und bis in den Talbereich vorstoßen, sind trotz allem nicht zu erwarten; eine Beeinflussung des Siedlungsraumes und der Infrastruktureinrichtungen durch Lawinen aus dem Wald ist daher im Moment wenig wahrscheinlich (Höller 2002).
Nach dem aktuellen Stand des Wissens gibt es derzeit keine eindeutigen Anzeichen, dass sich die Lawinenaktivität infolge klimatischer Veränderungen wesentlich verändert. Laut dem Schlußbericht des NFP 31 (Schneebeli, 1998) wird das natürliche Lawinenrisiko etwa auf gleichem Niveau bleiben.

LITERATUR

Altenhofer N. (Hrsg) 1996: Winterbericht 1995/96 des Lawinenwarndienstes Salzburg

Aulitzky H. 1961: Die Bodentemperaturverhältnisse an einer zentralalpinen Hanglage beiderseits der Waldgrenze. I.: Die Bodentemperaturen oberhalb der zentralalpinen Waldgrenze. Arch. Met. Geophys. Bioklim.B, **11**, 445-532.

BayForKlim, 1999: Klimaänderungen in Bayern und ihre Auswirkungen. Abschlußbericht des Bayerischen Klimaforschungsverbundes, Universität München, München,

Föhn P. 1991: Schnee und Lawinen. ETH Zürich, Versuchsanst. Wasserbau, Hydrol. Glaziol. Mitt. **108**, 33-48.

Föhn P. 1992: Characteristics of weak snow layers or interfaces. Proc. Int. Snow Science Workshop, 4-8 October 1992, Breckenridge, Colorado, 160-170.

Frey W. 1977: Wechselseitige Beziehungen zwischen Schnee und Pflanze – eine Zusammenstellung anhand von Literatur. Mitt. Eidg. Institut Schnee- und Lawinenforschung 34, 223 S.

Frey W. u. B. Salm 1991: Snow properties and movements in forests of different climatic regions. Proc. XIX IUFRO World-Congress Vol.**1**, Div.1, 328-339.

Gubler H. u. B. Salm. 1992: Der Anbruchmechanismus von Schneebrettlawinen und die Gefahrenbeurteilung eines Einzelhanges. Proc. Int. Symp. Ski Mountaineering, 7-12, 4, 1992, Rudolfshütte, Salzburg, 10-15.

Gubler H. und J. Rychetnik. 1991: Effects of forests near the timberline on avalanche formation. International Association of Hydrological Sciences Publication 205 (Symposium at Vienna 1991 - Snow Hydrology and Forests in High Alpine Areas), 19-37.

Höller P. 1997: Das Schneegleiten auf verschieden bewirtschafteten Flächen nahe der Waldgrenze. Centralbl. ges. Forstw, 114. Jhg., Heft 2/3, 97-108.

Höller P. 1998: Tentative investigations on surface hoar in mountain forests. Ann. Glaciol. **26**, 31-34.

Höller P. 2001a: The influence of the forest on night-time snow surface temperature. Ann. Glaciol. **32**, 217-222.

Höller P. 2001b: Snow gliding and avalanches in a south-facing larch stand. International Association of Hydrological Sciences Publication 270 (Symposium at Maastricht 2002 - Soil-vegetation Atmosphere Schemes and Large Scale Hydrological Models), 355-358.

Höller P. 2002: Avalanches in mountain forests and possible effects on hazard zoning in Austria. Data of Glaciological Studies **93**, 100-103.

Laternser M. und M. Schneebeli. 2002: Temporal Trend and Spatial Distribution of Avalanche Activity during the Last 50 Years in Switzerland. Natural Hazards **27**, 201-230.

Luzian R. 2002: Die österreichische Schadenslawinen-Datenbank. Forschungsanliegen-Aufbau-erste Ergebnisse. Mitt. Forstl. Bvers.Anst. **175**. 51 S.

Martin E., Giraud G., Lejeune Y. und Boudart. G. 2001: Impact of climate change on avalanche hazard. Ann. Glaciol. **32**, 163-167.

McClung D. u. Schaerer P. 1993: The Avalanche Handbook. The Mountaineers, 271p. Washington.

Schneebeli M., Laternser M. und Ammann W. 1997: Destructive snow avalanches and climate change in the Swiss Alps. Eclogae Geologica Helvetiae, **90 (3)** 457-461.

Schneebeli M. 1998: Wechselwirkungen zwischen Klima, Lawinen und technische Maßnahmen. Schlußbericht NFP 31. vdf - Hochschulverlag Zürich, 132 S.

Salm B. 1978: Snow forces on forest plants. IUFRO Seminar Mountain Forests and Avalanches, Davos, 157–181.

UBA 2004: Auswirkungen von Klimaänderungen auf den Wald. Homepage des Umweltbundesamtes Wien. http://www.umweltbundesamt.at/umwelt/wald/klimawandel/auswirkungen

Zenke B. 1985: Lawinenstriche im Bergwald. Verein zum Schutz der Bergwelt, Jahrbuch 50. Jhg. 49-63.

IMPLEMENTATION, APPLICATION AND ENFORCEMENT OF HAZARD ZONE MAPS FOR TORRENT AND AVALANCHE CONTROL IN AUSTRIA

IMPLEMENTIERUNG, ANWENDUNG UND VOLLZIEHUNG DER GEFAHRENZONENPLÄNE ZUR KONTROLLE VON WILDBÄCHEN UND LAWINEN IN ÖSTERREICH

Florian RUDOLF-MIKLAU and Franz SCHMID

Federal Ministry of Agriculture, Forestry, Environment and Water Management,
Department IV 5, Torrent and Avalanche Control

ABSTRACT

The paper outlines the legal and technical bases of hazard zoning (protection from torrents, avalanches and erosion) in Austria and gives a summary of the implementation, application and enforcement of hazard zone maps in development planning, as a prerequisite for effective protection measures and a steering instrument for safety planning. The legal effects of hazard zone maps according to the regulations implementing the 1975 Forest Act and their enforceability within the bounds of Development Planning Acts and Building Acts are discussed. In addition, possible ways of improvement are considered. From the technical point of view the article focuses on the significance of the return period for hazard zoning and the understanding and treatment of the design event and the effects for hazard zoning criteria. The hazard zone map in combination with an obligatory development scheme turns out to be a very efficient tool to enforce object protection (building protection) measures in endangered areas (within hazard zones). The hazard zone map as an instrument for safety planning and crisis management is used only occasionally in Austria. Implementation depends on the availability of hazard zone maps in digital form nation-wide.

KEYWORDS: hazard zone map, torrent and avalanche control, Forest Act, natural hazard management, development planning, design event, precautions for existence, object protection, crisis management

ZUSAMMENFASSUNG

Die Arbeit beschreibt die rechtliche und technische Grundlage der Gefahrenzonenplanung (Schutz vor Wildbächen, Lawinen und Erosion) in Österreich und beschreibt die Implementierung, Anwendung und Vollziehung der Gefahrenzonenpläne bei Planungen als Voraussetzung für Schutzmaßnahmen and als Lenkungsinstrument. Die rechtlichen Wirkungen der Gefahrenzonenpläne nach dem Forstgesetz 1975 und deren Durchsetzbarkeit innerhalb der Raumplanung und Bauordnung werden diskutiert. Mehrere Verbesserungen werden erwogen. Aus technischer Sicht wird die Bedeutung der periodischen Wiederholung der Gefahrenzonierung, das Verständnis und die Behandlung des Muster-Ereignisses und die Auswirkungen der

Zonierungskriterien beschrieben. Der Gefahrenzonenplan gemeinsam mit dem verpflichtenden Entwicklungsplan erweist sich als effizientes Werkzeug für den Objektschutz (Gebäude) in gefährdeten Gebieten innerhalb der Gefahrenzonen. Der Gefahrenzonenplan wird in Österreich nur gelegentlich als Instrument der Sicherheitsplanung und des Krisenmanagements verwendet. Die Durchsetzung hängt von der Verfügbarkeit digital gespeicherter Gefahrenzonenpläne in Österreich ab.

SCHLÜSSELWORTE: Gefahrenzonenplan, Kontrolle von Wildbächen und Lawinen, Forstgesetz, natürliches Gefahrenmanagement, Entwicklungsplanung, Musterereignis, Objektschutz, Krisenmanagement

INTRODUCTION

Protection against torrents, avalanches and erosion in Austria: precautions for existance

Natural hazards represent a major safety risk in the mountain regions: Torrents, avalanches, debris flows, landslides and rock-fall threaten people, their living area, settlements and infrastructure (facilities). Existential fears have has a considerable impact on the thinking of people in a modern society. With increasing demands for prosperity and quality of life the need for safety also increases. Various threats go out of natural hazards for the basic functions of living (work, supply, education, leisure, traffic and communication). The individual cannot protect himself all alone against these threats. In view of the growing protection demands of the population the state has taken care of the precautions of existence also in this sector (Rudolf-Miklau, 2003).

According to the Austrian Constitution (B-VG 1920) the protection against torrents and avalanches (Article 10) (literally “torrent control”, avalanche control included) falls within the competence of the Federal Government (Bobek et al., 1995). On the one hand, subsidies are granted by the Government (Federal Disaster Relief Fund) and the Provinces for preventive measures. On the other hand area planning is influenced by means of the instrument of the hazard zone map (1975 Forest Act).

The effects of the hazards caused by torrents, avalanches, debris flows, landslides and rock fall are characterised by high flow velocity, strong forces as well as the deposition of huge masses (rocks, gravel, wood, snow). Disastrous events frequently occur in connection with extremely heavy precipitation. The events occur quickly and without any warning and have an enormous destruction potential. This means a serious danger for people both outside and inside of buildings. Severe losses are caused by the destruction or damage to buildings, highways and vehicles or the interruption of supply lines. The great forces and pressure of debris flows, avalanches or rock falls represent another special threat. Floods may also impair the stability of slopes, buildings and streets by triggering erosion processes. Movements appearing in landslides set pulling force and pressure strengths on buildings and can lead to their collapse. There is danger also for the inventory of buildings, for the vehicles parked in garages or heating systems in cellar rooms by penetrating water, snow or mud (Egli, 1999).

The best protection measure is undoubtedly to avoid hazardous areas. Due to the strong demand for space (building area, trade and industry, traffic ways, tourism, agriculture and forestry) in many mountain regions on the one hand and the effects and superposition of natural hazards on the other hand, there are almost no more areas available offering a high degree of safety (Leitgeb and Rudolf-Miklau, 2003).

Forest stands fulfil an important protective function on steep mountain slopes. They protect settlements and infrastructure whereas its effect is also limited because of the extreme site conditions. The protective effect of the forests must therefore be enhanced and completed by silvicultural measures. Technical and biological protection measures, artificial triggering of avalanches, measuring and warning systems, information and advice, alarm, evacuation, closure or the catastrophe service, count among the most useful modern instruments of natural hazard management in addition to hazard zoning. The individual can achieve efficient protection of his own building or property (object protection) with relatively low technical effort. This applies both to new buildings and to existing buildings which are to be reinforced (Rudolf-Miklau, 2003).

Instruments for natural hazard protection: precautions taken by the Federal Government and by the citizens

In Austria, the state provides a well established system for natural hazard protection. The use of hazardous areas is subject to legal restrictions and development planning. Public subsidies can be granted for projects which protect existing settlements and infrastructure and where the cost exceeds the financial capacity of the individual.

The provisions for the protection against natural hazards are laid down in the Forest Act, the Water Act, the Torrent Control Act of 1884 (still partly in force), the Building Acts and the Development Planning Acts.

Other important legal regulations in Austria having direct effects on natural hazard protection and disaster management are summarized in the following table:

Measures	Competence	Legal basis	Notice
Land use planning	Communities municipalities	Land Use Planning Acts	Legislation and official supervision by the provinces
Building affairs	Building authority of the communities	Building Acts	Legislation and official Supervision by the provinces; authority has to hear experts in hazard management
Protection of roads	Road departments of the provinces Federal motorway company for the freeway and speed ways	Road Construction Act	Financial support for the protection and maintenance of roads related to natural hazards form the disaster relief fund (partly)
Protection of railroads	Federal railroad company	Rail Road Act	
Tending of protection forests, high altitude afforestation	Owner of the forest Financial support from the federation and the provinces	Forest Act	Supervision by the district authorities
Cable Ways	Federal Ministry of Traffic, Infrastructure and Technology for legislation and permissions	Cable Way Act Ordinance for Avalanche Safety of Cable Ways	Expert commission by the Federal Ministry of Agriculture, Forestry, Environment and Water management
Closings	Public roads: task of the road departments (provinces), motorway companies or communities Private roads and skiing areas: task of the person responsible for the safety and maintenance of the road (skiing area)	Road Traffic Act Civil Code Ordinances of local police authorities	Decisions due to the expert opinion of commissions (e. g. local avalanche comissions)
Evacuations	Major of community or director of the district administration board (district authorities)	Safety Police Act Building Acts Catastrophe Act Ordinances of the local police authority	Evacuation plans of the provinces and communities
Avalanche warning services	Departments of the provinces		
Avalanche commissions	Communities	Civil Code Catastrophe Acts Avalanche Commission Act of the Province of Tyrol Standing orders for the avalache commissions by the communities	
Nature conservation	Authorities of the district administration	Nature Conservation Acts of the Provinces	

In Austria, protection measures from torrent, avalanches and erosion are annually funded with € 69 billions from the Federal Disaster Relief Fund and through subsidies of the provinces. The Austrian Forest Engineering Service in Torrent and Avalanche Control, a body of the Federal Ministry of Agriculture, Forestry, Environment and Water Management, is responsible for hazard zoning, planning, construction and maintenance of protection measures (technical, biological and silvicultural measures), urgent measures after catastrophic events as well as advice and expert opinion (Fiebiger and Rudolf-Miklau, 2003).

In a modern society an increasing loss of initiative for the voluntary and independent take-over of public and social services can be observed. The fulfilment of tasks like, the protection against natural hazards is expected and called for with emphasis by the Federal Government, the provinces and the municipalities with increasing emphasis. Risk acceptance, the informed decision to accept a certain risk, decreases constantly at the same time. In principle, every citizen, who stays, moves, settles or builds in a zone threatened by natural hazards shares the responsibility for his own safety and those of the neighbours. Although in Austria the protection against natural hazards falls within the competence of the Federal Government according to the Federal Constitution, every beneficiary of preventive measures must make an adequate contribution (Rudolf-Miklau, 2003). This contribution does not only consist in a financial share to sponsored protection measures (for example in the legal frame of water co-operative societies on the basis of § 73 of the 1959 Water Act), but also in the execution of object protection measures or the individual insurance against damages by natural disasters. However, own precautions also presuppose a responsible behaviour dealing with the risk by natural hazards. This includes the raising of awareness, the perception and acceptance of risk conditioning its subordination under the fixed rules of area planning and safety regulations.

All these facts underline the great importance of foresighted land use and development planning taking into account natural hazards and a comprehensive natural hazard management approach which includes all modern instruments suitable to prevent disasters (protection measures, tending of protection forests, foresighted crisis management). The above leads us to the function of hazard zone maps as a substantial steering instrument.

The planning and implementation of hazard zone maps in development planning, building trade and safety planning but also their impact on policy, economy and society have been a subject of intensive discussion in Austria during the last two years. The social and economic changes taking place in the Alpine region as well as the consequences of the avalanche catastrophe 1999 and the floods 2002 have led to fundamental considerations, whether the existing guidelines, the used planning tools and the legal provisions on hazard zone plans are sufficient to guarantee an optimal protection against floods, torrents, avalanches and erosion. Questions concerning the residual risk, the advantages/disadvantages of a possible legal liability of hazard zone maps, their function in active protection measures (e.g. recovery of natural flood retention areas) were raised. The role of hazard zone maps for development planning and object protection measures in endangered areas as a key requirement for the subsidization of preventive measures or reconstruction support after catastrophes has been discussed but still no definite solution could be reached. Nevertheless, the Federal Ministry of Agriculture, Forestry, Environment and Water Management has set up one major goal for hazard zoning for torrent and avalanche control which is to achieve full coverage of Austria with hazard zone maps by the year 2010 (Schmid, 2003).

The experiences of the flood 2002 lead to the conclusion, that there is no way but to make an effort to improve the political and legal enforceability of hazard zone maps. At first sight, it seems clear that hazard zone maps have to reach legal liability in development planning, building trade and safety planning. The efficiency of hazard zone maps seems to be only a function of clear competences, legal regulations and comprehensive natural hazard management, but in practice a lot of problems have to be faced that cannot be solved by these measures alone. The paper shows also other instruments for successful implementation of hazard zone maps and possible ways of improvement.

Basis and application of hazard zone maps in Austria - The legal basis of hazard zoning

In accordance with the provisons of the Austrian Forest Act (1975) § 8 b and § 11 (2) , catchment areas and the zones endangered by torrents and avalanches as well as reserved zones have to be designated in hazard zone maps and preventive measures have to be planned accordingly. Detailed regulations concerning the design of hazard zone maps are laid down in the Ordinance on Hazard Zoning of 1976 (Kalss, 1990).

Although according to the legal definition the hazard zone map is an instrument of the "development planning of forestry", in addition to the forest land, it comprises all other areas that can be considered catchments of torrents and avalanches according to the Forest Act (Bobek et al., 1995). Hazard zoning affects directly the General Development Plan and, in accordance with § 3 of the Ordinance on Hazard Zoning, covers all properties which are endangered by torrents and avalanches.

The catchment areas of torrents and avalanches are the basis for the designation of the natural dangers in the hazard zone map, in accordance with Forest Act § 99. The most important protection category are hazard zones which mark the areas endangered by torrents and avalanches to such an extent that a permanent use for settlement and traffic purposes is not possible or only possible with unproportionally high effort (red zone) or their use being at least impaired (yellow zone). The other zones outlined in the hazard zone maps are: blue reservation areas which are reserved for future protection measures by the Austrian Forest Engineering Service for Torrent and Avalanche Control; brown reference areas which inform about other natural hazards than torrents and avalanches like landslides and rock-falls without assessing the intensity and frequency of an event; purple reference areas which show the protection function dependent on the soil composition (terrain); (Schmid, 2003).

The specification of hazard zones, reservation areas and areas indicating other natural hazards is carried out on the basis of state-of-the-art methods, the personal experience of the planner, the documentation of historical catastrophe events (torrent and avalanche chronicle) and the performance of possible disaster events (scenarios) which are expected with a recurrence period of 150 years. According to § 5 (2) of the Ordinance on Hazard Zoning, hazard zoning has to consider not only all available data, information and interactions concerning natural hazards but also risks through human interventions which change and influence the balance of nature (e.g. skiing areas, traffic ways, settlement development, pollution, climate change). The plan finally has to contain suggestions for the improvement of the protective functions in the areas concerned (Kalss, 1990).

In accordance with § 11 of the Forest Act, the Federal Minister of Agriculture, Forestry, Environment and Water Management has to prepare and to change (revise) hazard zone maps using the offices of the Austrian Forest Engineering Service in Torrent and Avalanche Control (Forest Act § 102). A hazard zone map covers the area of a municipality or parts of it. The outline of the hazard zone map is submitted to the mayor of the municipality and has to be displayed to the public for four weeks at least. Everyone who can assert a legitimate interest has the right to bring in objections in the form of a written statement to this outline. After the expiration of the period a commission consisting of a representative of the Federal Ministry of Agriculture, Forestry, Environment and Water Management, the Province, the headquarters of the Austrian Forest Engineering Service in Torrent and Avalanche Control in this province and the municipality has to check and to amend the plan, if need be, taking into account all incoming written comments.. The hazard zone map is approved by the Federal Minister of Agriculture, Forestry, Environment and Water Management. The approved hazard zone map has to be made accessible to the public at the offices (in accordance with § 102 of the Forest Act) and a copy has to be submitted to the province, the district administration authority and the municipality each.

According to the General Co-ordination Order of the Forest Act § 6 (2), the hazard zone map has to be based on comprehensive data material. Broad co-operation which guarantees that it is widely recognized has to be strived for An exemplary regulation of the citizen participation has been created very early by the regulations of the 1975 Forest Act, with regard to the examination and approval method, being completed in the planning phase by informal hearings and presentation events. Finally, broad agreement and public acceptance of this central planning tool for natural hazard management is sought. (Kalss, 1990).

The legal effects of hazard zone maps for natural hazard protection

After predominant interpretation of law hazard zone maps don't have any ordinance character (Khakzadeh, 2004) and for this reason, the application of hazard maps does not lead to any commandment, prohibition or permission (Zopp, 2004). Additionally, it is reported in literature, that the hazard zone map has the character of an instruction what corresponds to the opinion that a "sovereign act" is performed, too (Kalss, 1990).

The plan is to be worked out by an office according to § 102 of the Forest Act (Austrian Service for Torrent and Avalanche Control), which in principle cannot be considered an authority but is only a subordinate body of the Federal Ministry of Agriculture, Forestry, Environment and Water Management. The approval of the hazard zone map by the Federal Minister subsequently does not have any normative content, it is just the the technical correctness (Bobek et al., 1995).

According to § 1 of the Ordinance on Hazard Zoning, it is the basis for the planning and execution of the protection measures of the Austrian Service for Torrent and Avalanche Control for the ranking of these measures according to their urgency (priority list). Hazard zone maps have to be elaborated in such a way (according to the Ordinance on Hazard Zoning § 1 (2)), that they can serve as a basis of general development planning, building trade and safety planning (Schmid, 2003). The participation of a representative of the province and the municipality at the examination of the hazard zone map by the commission does not make the plan obligatorily yet, but ensures that the hazard zone map is accepted so that to make it a "directive" from which can only be deviated for sound reasons (Kalss, 1990).

Furthermore, another legal effect can be noticed, namely the liability for subordinate planning institutions. For example the Development Planning Acts of the provinces may contain provisions according to which the development plans of the municipalities must not be inconsistent with the planning of the Federal or the Provincial Government. Further provisions may require the inclusion of hazard zone maps in development planning. The hazard zone map gets a binding effect through the display of red and yellow zones in the development plans of the municipalities or a reference in the affiliated document to the hazard zone map (Kannonier, David, 2003).

An actual acceptance of the hazard zone map was reached through provisions related to the administration of public subsidies in the field of torrent and avalanche control. According to Section II of the "Directive for the Handling of Impediments for Use of Subsidies of the Federation for Torrent and Avalanche Control", (Bobek et al., 1995) released by the Ministry of Agriculture, Forestry, Environment and Water Management, no subsidy must be granted for the torrent and avalanche control if the hazard zone maps are not taken into account in other sectors of planning. This regulation concerns all subsidies based on the Water Constructions Financing Act (1985), the Forest Act and other subsidies available to the Ministry for Agriculture, Forestry, Environment and Water Management. But the liability for beneficiaries and other planning does not change the weak normative content of the hazard zone map as such (Kalss, 1990). It can be summarized that due to jurisdiction the hazard map actually is an expert opinion with the character of a forecast (Zopp, 2004).

The "design event" and the valuation of delimitation criteria in hazard zoning of torrent and avalanche control

Hazard zoning in torrent and avalanche control and flood control in Austria is based on separate regulations and different ways of execution.. In addition, a different type of planning culture has developed in the past. For this reason, it is worthwhile to compare the criteria for hazard zoning for rivers and torrents and the "design event" approach.

In Austria, flood protection measures are based on an expected return period of 100 years. This corresponds to the flow (run-off) which is exceeded on average every hundred years at a defined location. Since it is a mean average value, this flow can appear also repeatedly within a hundred years. If measuring time periods contain years less than 100 years at rivers, the flow (run-off) is calculated statistically. The level lines of floods with 100-years return

periods can be calculated with the help of hydraulic simulation and on the basis of high-resolution topographic models and can be considered definitely and objective in an satisfactory extent, when the transport of bedload and woody debris is neglected. The criteria for the delimitation of hazard zones in flood protection refer primarily to the flowing depth and the flowing velocity (or flowing velocity and tension due to traction) of the flood-wave at her climax according to the existing Technical Guidelines for Flood Control (RIWA-T).
In accordance with the regulations of the Ordinance on Hazard Zoning § 6, hazard zones have to be determined taking into account an event with a probability of recurrence of approx. 150 years (**design event**). Additionally, a "frequent event" in the "Directive for the Hazard zoning", released by the Federal Ministry of Agriculture, Forestry, Environment and Water Management with a probability of recurrence of 10 years was defined (Schmid, 2003).
Especially regarding the alluvial fan, the typical form of deposition in a torrent catchment, the assessment of natural hazards has to take into account a variety of processes and superposing process chains, which yield a wide range of possibilities for the development of a catastrophic event corresponding to a period of recurrence of 150 years (Rudolf-Miklau, 2001).
In hazard zoning scenarios count among of the most important tools for the expert (planner) in decision making (Loat, Petraschek, 1997). Therefore, the determined hazard zones represent an expert decision for the sum line of all possibilities in the case of the occurrence of a design event (catastrophic event). The sum line has to be given detailed reasons in writing for by the planner (Schmid, 2003). It clearly turns out that a "calculation" of hazard zones, for example by means of a hydraulic model, due to the state of the art is practically not possible in torrents in harmony with objective criteria and with the aim of a definite result. This is also true for the assessment of hazards due to avalanches and erosion (slope movement, rockfall). Nevertheless, the "Directive for Hazard Zoning" contains quantitative criteria for torrents and avalanches. In practice mostly several criteria have to be taken into account at the same time due to the complexity of torrent processes. Due to the catastrophic events of Galtür and Valzur in 1999 the limit for red zones was defined by an avalanche pressure of 10 kN/m^2.

Delimitation of flood and debris flow events (TR = Torrent-Red, TY = Torrent-Yellow)

Criteria	**Zone**	**Design event**	**Frequent event (1 to 10 times/year)**
1) Stagnant water	TR	water depth ≥ 1,5 m	water level mark HQ10 > 50 cm, HQ 1>20 cm
	TY	water depth < 1,5 m	water level mark HQ10 > 50 cm, HQ 1<20 cm
2) Running water	TR	height of energy line ≥ 1,5 m	HQ10: height of energy line ≥25cm
	TY	height of energy line < 1,5 m	HQ10: height of energy line < 25 cm
3) Erosion gullies	TR	depth ≥ 1,5 m	erosion gullies possible
	TY	depth < 1,5 m	runoff without erosion gullies, thus see no. 2!
4) Bedload-deposits	TR	height of deposits ≥ 0,7 m	Bedload deposits possible
	TY	height of deposits < 0,7 m	no bedload deposits, thus see no. 2!
5) Post-failure slope movement consequently depth/lateral erosion	TR	Upper edge of the post-failure slope movement area	
	TY	safety distance	
6) Debris and earth flows	TR	boundary of marked debris flow deposits	
7) Retrogressive erosion	TR	possible extent	
	TY	take note of points 3 and 5	no assessment

Remarks: ad. point 1): bog pools, ponds, wells, small synclines are not represented

ad point 5)- Reason for the width of the safety distance in the individual case; - In order to record and define post-failure slope movement areas a check-list is being worked out

Delimitation of avalanche events (AR = avalanches-red, AY = avalanches-yellow)

Criteria	**zones**	**Design event**	**Frequent event (1-10x/yr)**
1) Pressure (p)	AR	$p > 10$ kN/m²	$p > 10$ kN/m²
	AY	$1 < p < 10$ kN/m²	$1 < p < 10$ kN/m²
2) Thickness at deposits (T)	AR	$T > 1,5$ m	$T > 1,5$ m
	AY	$0,2 < T < 1,5$ m	$0,2 < T < 1,5$ m

Fig. 1: The criteria for the determination of red and yellow hazard zones due to the "Directive for hazard zoning" released by the federal Ministry of Agriculture, Forestry, Environment and Water management.

Abb. 1: Kriterien für die Ausscheidung von roten und gelben Zonen (Direktiven BMLFUW)

Within the last few years a fundamental discussion has arisen around the significance of the "return period" of design events for the hazard zoning in torrent and avalanche catchment areas. Since the available observation period on catastrophic events on the one hand, statistically hardly suffice to yield valid data, and the complexity of process chains in torrents and avalanches on the other hand, the design event becomes hardly comprehensible in its return probability. Other possibilities of frequency and intensity presentation of the events were sought (Willi et al, 2002). Experts generally think that a statistically valid probability of reoccurrence is reduced to the precipitation event and even the period of reoccurrence of flow (run-off) can not be clearly correlated to this. Therefore, another viewpoint which doesn't depart from the process but from the intensity and the frequency of the damages has to be considered. Since also in this field narrow limits exist for prognosis of victims, damage and destruction due to the lack of data, this risk oriented approach is also not a general solution for the problem.

The problem of the recurring design event finally becomes even more complicated when considering existing protective measures at the natural hazard assessment (effectiveness, life time and period of effectiveness, condition). No general guidelines are available also in this field at present (Romang, 2003).

Hazard zone maps as a basis for planning and priorisation of protective measures

The planning of protective measures for torrents, avalanches and erosion is part of a comprehensive natural hazard management approach being based on an intensive analysis of the hazard potential (risk potential) in the catchment areas (Leitgeb, Rudolf-Miklau, 2003). In accordance with the Ordinance on Hazard Zoning § 1 (1), hazard zone maps are the basis for protection measures planned and conducted by the Austrian Service for Torrent and Avalanche Control. They are also the basis for the priority ranking of these measures according to their urgency. Thus, a planning culture has developed, which is based on protection concepts, that cover in a direct line the risk assessment, the hazard zoning and the preventive measures. Part of the system is, however, also a feedback of the experiences and a regular quality improvement for the planning processes. The hazard zone map is the central tool to visualise hazard potential and protection deficits and serves as an economic proof (basis of the cost-benefit-analysis) and a key requirement for federal subsidies. The hazard zone map is also used as a foresighted and retrospective proof of the success of protective measures (Reiterer and Rudolf-Miklau, 2002).

The limited availability of public subsidies requires a definition and enforcement of priorities during the planning phase. Although a lot of information is derivable from the hazard zone map for the ranking of protective measures according to their urgency, there are no established methods and criteria for the execution of priority ranking available until now. However, this steering instrument will gain in importance due to the developments in the public households. The demand for comprehensible acting and transparency concerning the decision processes in the field of subsidisation for torrent and avalanche control can also be seen as an essential challenge of the future. The order for the execution of priority ranking has been fixed in the new version of the "Technical Directive for the Torrent and Avalanche Control" (TR-WLV) in Austria.

At present, there exists the draft version of a guideline for priority ranking of torrent and avalanche control projects, which shall be tested by the Austrian Forest Engineering Service for Torrent and Avalanche Control in the near future. For the time being, priority ranking of projects eligible for funding, is based on the following criteria:

- Protection of human life in settlements and other facilities
- Protection need of goods: building, facilities, traffic ways, infrastructure, supply lines (existing protection needs go in front of newly arising protection needs)
- Cost-benefit-relation
- Menacing rise of the hazard potential due to natural developments in a catchment of risk area
- Return period or probability of reoccurrence
- Other public interests

The close connection between hazard zoning and planning of protection measures has proved to be very efficient in the past having guaranteed the sustainable use of public subsidies from the disaster relief fund. In combination with the "impediment guideline" an effective system for the enforcement of hazard zone maps was created.

The enforceability of hazard zone maps in development planning

Development planning falls within the competence of the Provinces in legislation and execution in accordance with the Austrian Federal Constitution (Funk, 2003). In most Development Planning Acts hazard protection (especially the protection of the population, facilities and infrastructure from natural hazard, e.g. in the Styrian Development Planning Act § 3 (2)) is particularly designated as objective. In connection with protection against natural hazards, development planning has to accomplish three essential tasks (Rauter, 2001):

- Consistent consideration of the natural hazards at the specification of area uses
- Prevention of developments in land use, that would lead to an unacceptable rise of the risk potentials enabling alternatives to intended development of areas exposed to natural hazards
- Contribution to the realisation of integral protection strategies for example by the preservation of natural flooding areas (flood retention areas)

Clear priority rules for the aim "protection from natural hazards" are generally missing in development planning acts in Austria.

In development planning, hazard zone maps are applied in accordance with modern development planning acts of the provinces at several levels:

At the level of supra-regional development planning , development programs and concepts to be passed by the provincial government represent instruments, into which specifications with local or sectoral reference can be integrated and which are necessary for the goal of "natural hazard protection". Obligatory translocal development programs have not been carried out by far in all Austrian regions. The specifications of regional development programs are more of a general nature, e.g. Carinthian Development Planning Act § 3 (3) lit 5, and can, therefore, under no circumstances be related to the property in the land register. The experiences show until now, that the effectiveness of translocal development planning concerning natural hazards had only limited success. The consequences of the flood disaster 2002 suggest though, that development planning measures will only be successful, if they exceed the limits of local interests (covering all municipalities in the region/ along a river). It is finally of great importance that translocal development planning taking into account natural hazards is legally-binding and not only – as usual – just serves for information (Kannonier and David, 2003).

The level of local development planning is of primary importance for the enforcement of a hazard zone map. Already in local development concepts (settlement concept, green land concept) which are not always legally-binding or do not have any ordinance character for the municipalities, fact finding must also include hazard zone maps. However, of major importance is a regulation which makes the display of hazard zones (areas endangered by natural hazards) obligatory for new development plans and makes information better available to the public (e.g. Tyrolean Development Planning Act 1997 § 35 (2)) (Rauter, 2001).

The development plan has become the most important planning document of the local development planning and serves the spatial order and development of the municipality. In connection with the legally specified obligation for display of hazard zones, the development plan gains major importance for the examination of development areas for its suitability as building land. According to the political goals of development planning, it serves the prevention of building in endangered areas and the aim to encourage settlement development at locations which are not endangered. Active planning measures by means of the development plan are only very restrictedly possible since an obligatory category isn't provided by reserved areas for special protective measures or rights for direct intervention in existing structures cannot be deduced. The presentation of hazard zones in the development plan serves only for information purposes (Kannonier and David, 2003).

In Austria, every development planning act contains regulations concerning a dedication ban (dedication restriction) for areas which are not (restricted) suitable for building purposes because of their natural conditions (natural hazards). This applies primarily to the dedication category "building land". Dedication bans which particularly aim at the risks by torrents, avalanches, debris flow, rock-fall, landslide and floods, are contained in most development planning acts. The official approval of the development plan by the supervising authority of the provincial government has to be denied, for example, if a ban regulation is ignored by the municipality for the building land dedication (Kannonier and David, 2003).

The rules for the dedication of building land in the "yellow zone" are laid down in a regulation of the Tyrolean Development Planning Act (§ 37 (2)). It says that the dedication for building land may be made only under the condition that a certain situation or construction of the building or other measures of building protection mitigates the risk by natural hazards (Rauter, 2001):

- Situation within an existing coherent settlement area or immediately after and
- no expansion of building land towards more strongly endangered areas (no development towards growing hazards).

Generally, dedication bans and restrictions do not include any direct reference to hazard zone levels (red and yellow zones, flooding zones with a 30 year return period). Therefore individual expert opinions are required. For this reason the dedication of building land within a yellow zone is depending on a positive expert report and is in general possible. But in practice more and more provinces reject the dedication of new building land in yellow zones and oblige the municipalities to look for alternatives in not endangered areas. The Development Planning Act of Vorarlberg e.g. provides in § 13 (2) an exception for the dedication of building land in endangered areas, if the measures for the prevention of such dangers are technically possibly and economically acceptable. Other development acts include similar exceptions (redevelopment area); (Kannonier and David, 2003).

At the announcement of a new hazard zone map frequently valid dedicated building land cannot be used for building any more (in most cases within the red zone). As a rule, these areas have to be rededicated at the revision of the development plan, so that they are no longer building land (due to a legal regulation or on pressure of the supervisory authorities). Since the possibilities of land use have great influence on the value of a property (ratio of the price of building land to green land per sqm), the owners of the land are not ready to accept regulations. They seem to them as an intervention of the state into private property. This leads to special conflicts between owners concerned and the municipality. Therefore the pressure for protection measures grows very fast in these areas and the property within the hazard zone is often declared redevelopment area. Alternatives exist by means of financial compensation paid to the owner by the municipality, but in most cases compensations of depreciation of property due to natural hazards is prohibited by law (Kannonier and David, 2003).

In the same way the development scheme, which lies in planning priority subordinate to the local development concept and development plan - not contradicting these plans - has an important function concerning natural hazard protection. The actual possibilities for the specification of structural design criteria (object protection) are considerably high in provinces in which the building permission is dependant on the obligatory preparation of development schemes.

In this planning document the compliance with the red hazard zone is achieved by marking the building borders or convergence lines in particular. Some development planning acts also allow to keep parts of the planning area free of buildings. The specification of a special building style is particularly effective for the avoidance of natural hazards (e.g. elevation of the ground floor to the surrounding terrain in order to avoid penetrating water). By means of this regulation building protection measures can be established corresponding to the risk of damage. Altogether, the development scheme allows the realisation of protection concepts adapted for the whole development area.

Especially in the past the implementation of hazard zone maps in development planning has lead sometimes to negative results. With a diminishing acceptance of the risk due to natural hazards the pressure to realise technical protection measures rose primarily in tourist areas in order to preserve the best possible safety and to allow further structural and economical development. Most land owners expect from technical protection measures, that after their completion red and yellow zones are reduced very soon. This trend is to be considered as extremely problematical, especially from a development policy point of view. In line with the goals of subsidisation policy technical protective measures shall primarily serve to improve the safety of an existing settlement area. They should not be used to gain new building land. For long term protection measures, limited period of effectiveness and a residual risk still remains especially for events above the design event (Rauter, 2001; Kalss, 1990).

The enforceability of the hazard zone map in building trade

All Building Acts (Building Regulations) of the Austrian provinces contain provisions regarding natural hazards. The building acts regulate how for a specific building scheme the suitability and building permission for a site for building can be achieved under consideration of the safety of the building itself and the location of natural hazards (Kannonier and David, 2003).

As a rule, building schemes in hazardous areas are not suitable for permission. In most building acts in Austria an obligatory declaration for a site concerning the suitability for building purposes and the priliminary examination by the building authority prevents building schemes in endangered areas from reaching the official hearing for the building permission. Only, if in case of substantial danger sufficient protection can be reached by the situation of the building other preventive measures (object protection), a permission for new building or rebuilding can be granted.

Direct references to the hazard zone map are missing except for the Tyrolean Building Act. But the hazard zone map gets effective indirectly via the development plans as a basis for the consideration of natural hazards. The specifications of the development plan and development scheme are legally-binding. General specifications regarding object protection against natural hazards are missing in the building acts. Equally, no general directive is available in Austria on this topic (There are guidelines on object protection available in Switzerland (Egli, 1999)). The building authority depends therefore on the expert opinion of special departments (Austrian Service for Torrent and Avalanche Control) or civil engineers at the specification of object protection measures. Building permissions by the authority have the legal force of an ordinance, thus the object protection measures laid down in these documents have to be carried out obligatorily by the building-owner. If these measures are based on an expert opinion of a representative of the Austrian Service for Torrent and Avalanche Control and they are not executed (but neglected) by the building owner, an impediment for the support of torrent and avalanche control measures for this catchment arises (Schmid, 2003).

The hazard zone map as a basis for object protection measures (building protection)

In principle, it will be necessary to clarify at any planned building and land use activity in areas endangered by torrents, avalanches or erosion, whether the plan is compatible with the risk and whether the effort for the protective measures is technically and economically acceptable. Besides their protection effect object protection measures should be in harmony with the use of the building. Existing buildings should be examined for possibilities of improved object protection, too (Rudolf-Miklau, 2003; 2004).

Tab. 2.: Examples for object protection measures against torrents, debris flow, avalanches, land slides and rockfall (after EGLI (1999, 2000)).

Object protection measure	tor-rent	deb-ris flow	land slide	rock -fall	ava-lan-che
Concept for the use of the site of building (opening up area)	●	●	●	●	●
Design of the form and situation of the building	●	●	●	●	●
Adaptation to terrain		●		●	●
Concept for the use of the interior rooms	●	●		●	●
Level and orientation of basement floor, cellar windows, doors etc	●	●			
Situation and size of windows and doors	●	●	●	●	●
Protection of building openings (increased cellar shafts, insulation of gates, windows, protective barriers, pressure density window)	●	●		●	●
Concept for the use of the outside area		●		●	●
Selection of building material	●				
Enforcement of walls exposed to pressure (reinforced concrete)	●	●		●	●
Framework for walls				●	
Sidecast slope in front of a wall exposed to dynamic pressure				●	●
Deep founding of the building	●	●	●		
Static concept of the whole building	●	●	●	●	●
Posts or anchorage of the foundation under the gliding surface of the landslide			●		
Support of the foundation in mass movement by posts or anchorage			●		
Enforcement of the roof truss				●	●
Layer of soil on top of the roof				●	
Concept for the supply lines	●				
Anchorage of oil tanks in cellars (rising water)	●				
Erosion protection for the foundation of the building	●				
Higher level of building site (compared to surrounding terrain)	●	●			
Deflecting wall, dam or fence	●	●			
Splitter (avalanche deflector), roof terrace ("Ebenhöh")		●			●
Regulated water run-off			●		
Drainage of mass movement			●		
Measures against suction (powder avalanche)					●
Combination of several measures listed above	●	●	●	●	●

The hazard zone map represents the most important source of information for the design and specification of object protection. As a rule, the hazard zone map contains all technical basics required for the arrangement and planning of object protective measures. The document also includes suggestions on the protection of buildings against the effects of torrents and avalanches. To be able to make a suitable concept for object protection, the type of damage effect must be known as well as the frequency and intensity of the process the assessment of which on the spot has to be carried out by an expert. The costs for object protection measures usually are very reasonable in relation to the total building costs so that the measures can be realised by the building-owner without difficulty receiving the necessary advice. Depending on the goal of protection a group of buildings, an individual building, parts of this or one or several properties are protected.

The implementation of hazard zone maps in local safety planning and crisis management in Austria

Hazard zone maps can serve as an effective basis (information source) for local safety planning, providing the basic principles for warning and evacuation plans and crisis management. Till now, these possibilities were hardly used, however, in Austria. The avalanche warning commissions most likely use the information from the hazard zone maps to be able to assess the situation of avalanche areas (run out lengths, propagation of avalanches) in order to estimate the area of necessary closings.

In the case of a crisis steering committees which usually are under the responsibility of the head of the district authority are formed at a regional level. Expert teams are established to which, as a rule, an employee of the Austrian Service in Torrent and Avalanche Control also belongs. For the justification of his expert opinion and as a basis for his suggestions to the steering committee he can use the hazard zone maps.

In Austria, initiatives are taken to build up computer-based crisis information systems. Based on geographical information systems, the hazard zones can be overlayed with other information and data, for example the number of persons to be evacuated in this area. Crisis information systems make it possible for the head of operation to control evacuation and rescue measures from a central and safe location and to make quick and efficient organisational arrangements on the basis of all available data. Such a system serves also the quick information distribution to the task forces. After the avalanche catastrophe in 1999 such a model (ESIS) has been established as a trial in the district of Landeck (Tyrol). The general introduction of such information systems still fails, because the problem of safe data transmission in case of a crisis has not yet been solved completely (Huber, 2002).

The basis of every computer based management system for natural hazard or crisis management is a comprehensive geographical information systems (GIS) as it was developed in all Austrian provinces in the last years (e.g. TIRIS in the province of the Tyrol, DORIS in Upper Austria, VOGIS in Vorarlberg). These systems contain all space related information on settlements, traffic ways, trade and industry, tourism, the borders of districts and communities, statistic, economic and demographic data and also the catchments of torrents and avalanches. Also regional data on natural hazards and the hazard zones are integrated in this system (Rauter, 2001). The main problem at the moment is the compatibility of data formats between the various information systems of the provinces, which has to be harmonised in order to achieve a nation wide data base for integrated crisis management. Also the capacity of memory and transmission for geographic information data is limited at the moment. In 2010, when full coverage with hazard zone maps will be reached throughout Austria, these problems should have been solved. Until then it will be also decided which parts of the geographic information can be opened to the public and which parts have to be reserved to an authorized section of users due to the legal requirements of data protection.

The hazard zone map as instrument for citizens' participation and risk communication

The importance of citizens' participation in the planning process of hazard zoning was already recognised and established very early in the provisions of the 1975 Forest Act . According to the General Co-ordination Order of the Forest Act § 6 (2), broad agreement and public acceptance of this central planning tool in natural hazard management has to be reached. The publication of the outline of the hazard zone map and the right of statement for everybody who can assert a legitimate interest correspond to the rules of modern participatory processes (Kalss, 1990). The planning process is further accompanied by several presentations and public hearings and supported by the close contact of the planner to the people affected by natural hazards.

Public acceptance of natural hazard management is not granted in all parts of Austria. Shortly after catastrophic events there is increased public awareness for natural hazards which decreases rapidly as time goes by. On the other hand the opposition against hazard zoning, which many people consider an interference of the state into their private property, can be strong, especially if economic interests are at stake.

In order to support public acceptance for hazard zone maps, this instrument has to be further developed to become a suitable tool for risk communication. The visualised hazards shall help people to learn about the risks in mountain regions and how to handle and live with the risk. The foresighted vision is that all people in our country feel responsible for natural hazard protection and are ready to contribute voluntarily to the prevention of disasters (Patek, 2002).

DISCUSSION

The growing importance of hazard zone maps in policy, economy and society is beyond all question. The existence of a legal basis for hazard zoning for torrent and avalanche control in Austria has turned out to be a great advantage in the past and supported the development of a nation-wide planning standard and a high area coverage with approved hazard zone maps. The traditional impeding of the hazard zone map in the Federal Forest Act has helped to develop this instrument towards an integrated part of torrent and avalanche control (federal competence in legislation and execution), but has also hindered a total integration into general development planning (competence of the provinces) . As hazard zone maps have practically no legal liability and the office in charge (Austrian Service for Torrent and Avalanche Control) has not the status of an authority, the acceptance of hazard zone maps by the provinces and municipalities is predominantly informal and inconsistent.

The "Directive for the Handling of Impediments for Use of Subsidies of the Federation for Torrent and Avalanche Control" has turned out to be the best instrument to enforce hazard zone maps. It makes the granting of subsidies from the Federal Disaster Relief Fund dependant on the consideration of hazard zone maps in development planning, building trade and other sectors of planning. The close connection of hazard zoning and the planning of protection measures have proved to be very efficient in the past securing at the same time the sustainable use of public subsidies. A new and important task will be the prioritisation of intended protection measures (projects). The hazard zone map contains information concerning this issue.

A major problem was the separated development of hazard zoning in flood control, where a legal basis like the regulations of the Forest Act is almost missing in Austria. There are also great differences in process and risk management, especially as regards the design event. Different criteria for hazard zoning in flood control and torrent and avalanche control are valid in Austria. While floods in rivers can be discribed reasonably by flow velocity and flow depth, in torrents complex process chains and interactions have to be taken into account. This makes the selection of the applicable hazard zoning criteria much more difficult. Furthermore, the design event in torrent catchments is not definitely a single one but hazard zones cover all kinds of possible scenarios of an event. In addition, the complex process chains make the significance of the "return period" of design events in torrent and avalanche catchments questionable. Therefore, other viewpoints have to be considered which do not depart from the process but rather from the intensity and the frequency of the damages but would not lead to an improvement of hazard zoning at the moment according to a lack of data in disaster documentation. One of the most important tasks for the future will be the harmonisation of hazard zoning in flood control and torrent and avalanche control on a technical and legal level, especially at the borders of competence.

The consequences of the flood disaster 2002 led to the conclusion that flood control is a task which can only be enforced on the translocal level of development planning in the sense of a comprehensive consideration of the total watershed and that supraregional development plans of the provinces with suggestive nature have fare too little effect on putting through the goals of natural hazard management. The Development Planning Act does not include any priority rule that prefer natural hazard protection to other planning interests.

In the process of enforcing a hazard zone map, the local development planning level is much more important. The well introduced instruments of the development plan and development scheme, in which the hazard zones have to be presented more or less obligatorily, are the most important sources of information on natural hazards and allow, in connection with the regulations on dedication ban and dedication restriction, an effective land use control in endangered areas. According to the provisions implemented in the Tyrolean Development Planning Act, the optimal situation is no further expansion of building land towards strongly endangered areas. Active planning measures by means of the development plan have proved to be possible only to a limited extent in the past, so that large-scale recovery of natural flood retention areas can hardly be put through without financial compensation.

The limited public acceptance for hazard zone maps, especially when newly determined red zones cover valid dedicated building land, has often been compensated by reimbursement or dedication of "redevelopment areas", pretending to mitigate the risk through torrent and avalanche control measures in the near future. These strategies point out a negative effect of implementation of hazard zone maps creating high pressure for additional protection measures. The lack in acceptance and approval of hazard zone maps can only be overcome by consequent risk communication and intensive citizens' participation. Legal tools are, as has been proved in the past, less suitable for this task.

The readiness of the people in endangered areas to take precautions on their own can certainly be increased by advice. The development scheme is an effective frame for the realization of protection concepts for development areas as a whole, as they allow to keep parts of the area free of buildings or prescribe a certain style of building. Development schemes are a useful tool the implementation of co-ordinated object protection measures.

In general, Building Acts refer to natural hazards in Austria but they do not have provisions on the suitability of building land to hazard zone maps. But due to the fact that the specifications of the development plan and development scheme are legally-binding, the implementation of hazard zone maps in building trade is quite efficient. As there are no general rules for object protection, the building authority depends on an expert opinion, a service, which is usually provided by the Austrian Service for Torrent and Avalanche Control. The hazard zone map represents the most important source of information for the design and specification of object protection. A building style adapted to natural hazards helps to reduce the risks for persons and property to a great amount.

While hazard zone maps are already widely used in development planning and building trade they are only occasionally consulted for safety planning, crisis management and risk communication in Austria. There might be a lot of reasons like divided competences, missing legal basis, lack of geographic information or deficits in data compatibility. But the main problem is still the lack of, the necessary organisational and technical structures. Better forecast and early warning systems will help to achieve progress in safety planning concerning torrents, avalanches and erosion hazards. The most important key requirement will probably be the nation-wide availability of hazard zone maps in digital form.

CONCLUSIONS

This paper gives a survey of the legal and technical basis of hazard zoning in Austria and summarises the possibilities for the effective application and enforcement of hazard zone maps. Since the regulations implementing hazard zoning in the 1975 Federal Forest Act have come into force, this important instrument has developed towards a comprehensive tool for natural hazard management. Two major questions raised in this paper: whether the hazard zone map should attain more liability and the significance of the "return period" of design events and valid criteria for hazard zoning in torrent and avalanche catchment areas, could not be solved and will be a subject of further discussions.

In general, the results of hazard zoning for development planning, safety planning and the management of federal subsidies from the disaster relief fund are quite satisfactory in Austria. Nevertheless, the paper points out a wide range of improvement possibilities, the most important of which. are summarised below:

1. The general co-ordination order of the Forest Act § 6 (2) has to be the basis for further development of hazard zone maps into an efficient tool of risk communication and crisis management.
2. The advantage of the obligatory consideration of hazard zoning in development planning and building trade as a key requirement for the approval of federal subsidies for protective structures in torrent and avalanche control will also be of great importance in the future. Better tools for the comprehensive management of subsidies and of existing impediments (data base) has to be developed.
3. An ordinance character or a normative content in hazard zone maps does not seem to be necessary for the successful implementation and general acceptance.
4. The recurrent design event should be described by scenarios rather than by quantitative dimensions (flow, bedload) only. In future, hazard zoning should also be based on the process, but the distraction potential, the differences in vulnerability and the risk acceptance should be taken into account.
5. The prioritisation of intended protection measures (projects) on the basis of the hazard zone map should develop to a planning standard.
6. Obligatory priority rules should be implemented into translocal and local development planning preferring the task of natural hazard protection to other planning interests.
7. The principle "no expansion of building land towards strongly endangered areas " should become an obligatory rule in development planning and building trade, without exception.
8. Development schemes should be declared legally-binding for all areas endangered by natural hazards to make co-ordinated safety planning and object protection possible.
9. The introduction of directives for object protection (building protection) against natural hazards seems to be an urgent matter.
10. The development of a nation-wide data base for crisis management, including full coverage with hazard zone maps (in digital form) is a major goal and should be achieved in Austria by 2010.

REFERENCES

Bobek, Plattner, Reindl, 1995: Forstgesetz 1975, 2. Auflage, Manz'sche Verlags- und Universitätsbuchhandlung.

Egli T., 1999: Richtlinie Objektschutz gegen Naturgefahren; Gebäudeversicherungsanstalt des Kantons St. Gallen.

Egli T., 2000: Objektschutz: Angepasste Bauweise reduziert das Personen- und Sachrisiko bei Gebäuden, Internationales Symposion INTERPRÄVENT, Villach (Österreich), Tagungspublikation, Bd. 2, 227-239.

Fiebiger G., Leitgeb M., 2002: National Reports on the Management of Mountain Watersheds 2000-2002 - National Report Austria, Mountain Watershed Management, Swiss Agency for Environment, Forests and Landscape, Berne.

Fiebiger G., Rudolf-Miklau F., 2002: Measures and programs considering to mountains – management of natural disasters, Mountain Watershed Management, Swiss Agency for Environment, Forests and Landscape, Berne.

Funk B.-C., 2003: Einführung in das österreichische Verfassungsrecht, 11. Auflage, Leykam Kurzlehrbücher.

Huber T., 2002: Crisis management in case of natural disasters, AJT workshop on River Watershed Management, Taiwan Disaster Prevention Society, Taiwan.

Kalss S., 1990: Forstrecht: Walderhaltung und Umweltschutz; Dissertation am Institut für Bürgerliches Recht, Handels- und Wertpapierrecht, Wirtschaftsuniversität Wien; Springer Verlag: Wirtschafts- und verwaltungsrechtliche Studien, Bd. 1.

Kanonier A., David C., 2003: Naturgefahren im österreichischen Raumordnungsrecht; Studie im Auftrag der Österreichischen Raumordnungskonferenz (ÖROK).

Khakzadeh L. M., 2004: Rechtsfragen des Lawinenschutzes; Neuer Wissenschaftlicher Verlag

Leitgeb M., Rudolf-Miklau F., 2003: Risk management in torrent, avalanche and erosion control in Austria; "Forests in sustainable mountain development", Internat IUFRO-Workshop, 9-13.6.2003, Galtür, Austria.

Loat R., Petraschek A., 1997: Berücksichtigung der Hochwassergefahren bei raumwirksamen Tätigkeiten (Empfehlungen), Bundesamt für Wasserwirtschaft (BWW), Bundesamt für Raumplanung und Bundesamt für Umwelt, Wald und Landschaft (BRP), (BUWAL), Biel (Schweiz).

Patek M., 2002: Leben mit Naturgefahren; Risikodialog – Naturgefahren erkennen, kommunizieren, akzeptieren; Bayrisches Staatsministerium für Landesentwicklung und Umweltfragen, Münchner Rück, 23. Juli 2003, München.

Rauter F., 2001: Raumordnungsinstrumente zur Prävention von Naturgefahren, Schutzwassersymposium, Alpbach (Tirol).

Romang H. et al., 2003: Berücksichtigung von Schutzmaßnahmen bei der Gefahrenbeurteilung; Workshop der Forstlichen Arbeitsgruppe Naturgefahren (FAN), 29. – 30. November 2003, Bad Ragaz, Schweiz.

Reiterer A., Rudolf-Miklau F., 2002: National strategies regarding the risks, caused by torrents, avalanches and erosion control, Internat Symp Sediment and Flood-related issues in Europe, Sion/Switzerland.

Rudolf-Miklau F., 2001: Untersuchungen an kohäsionslosen Sedimenten in kalkalpinen Wildbächen der Steiermark (Österreich), Dissertation, Universität für Bodenkultur.

Rudolf-Miklau F., 2003: Own precautions: An important individual contribution to the protection from alpine natural hazards; Conference Water and Society, BOKU Vienna, Nov. , oral presentation.

Rudolf-Miklau F., 2004: Objektspezifischer Hochwasserschutz im alpinen Bereich; Fachtagung des ÖWAV: Raumordnung und Hochwasserschutz, 21. – 22. 6. 2004, Wien.

Schmid F., 2003: Hazard zoning: Natural hazard management concerning torrents, avalanches and erosion; Conference Water and Society, BOKU Vienna, Nov., oral presentation.

Schmid F., 2003: Naturgefahrenmanagement zum Schutz vor Wildbächen, Lawinen und Erosion – Gefahrenzonenplanung; Acqua alta: Internationale Fachmesse mit Kongress für Hochwasserschutz und Katastrophenmanagement, Klima und Flussbau Neue Messe München 24. – 27. November 2003.

Willi H. P., Jordan J. P., Roth U., Frei B., 2002: Flood Control at Rivers and Streams, Richtlinien des Bundesamtes für Wasser und Geologie, Biel (Schweiz).

Zopp M., 2004: Naturgefahren im öffentlichen Recht, Gefahrenbegriff, rechtliche Instrumente und Haftungsfragen (mit Schwerpunkt Hochwassergefährdung); Diplomarbeit an der Paris-Lodron Universität Salzburg.

THE EFFECT OF ASHES FROM POWER PLANT AND ORGANIC WASTES ON THE GRASS GROWTH AND THE WATER QUALITY

DIE WIRKUNG VON ASCHE VON KRAFTWERKEN UND ORGANISCHEN ABFÄLLEN AUF DAS WACHSTUM VON GRAS UND AUF DIE WASSERQUALITÄT

Sławomir Stankowski[1], Jacek M. Łączny[2], Robert Maciorowski[1], Marek Matejczyk[2]
[1]Agricultural University, Department of Biometry,71-442 Szczecin, Papieża Pawła VI 3, Poland
[2]Institute for Ecology of Industrial Areas, 40-833 Katowice, Kossutha 6, Poland

ABSTRACT

In this paper we show the preliminary results (the first year of research) concerning the lysimeter study focused on the quality and quantity of the water percolating through the reclaiming layers, which consist of the ash-slag and mixture of ash-slag and the organic waste and the growth of the grass mixtures (perennial darnel- *Lollium perenne* L., red fescue- *Festuca rubra* L., meadow bluegrass- *Poa pratensis* L.) sown on the reclaimed object. High temperatures and a scarce rainfall during the vegetation period in 2003 resulted in no water percolation through the reclaiming layers in the model. This hindered the estimation of the chemical content of the percolates and the comparison of these with the content of the underground water naturally existent in the given area. No effect of the mineral fertilization of the ash-slag layer at the depth of 0,4 m below the soil surface was observed. The application of the fertile surface layer based on the sludge compost caused an increase of the photosynthetic capacity of the plants, which resulted greater biomass productivity as compared to an ash-peat surface layer.

KEY WORDS: fly ashes, sewage sludge composts, plant growth and biomass, photosynthetic capacity

ZUSAMMENFASSUNG

In einer Lysimeterstudie wurde der Effekt von Düngemitteln auf Aschenbasis und aus organischer Substanz auf das Pflanzenwachstum und auf die Menge und chemische Qualität von Perkolationswasser untersucht. Die Standorte waren mit verschiedenen Grasmischungen bewachsen. In der Vegetationsperiode des Jahres 2003 fand aufgrund der hohen Temperaturen und geringen Niederschläge keine Tiefensickerung im Boden statt. Dadurch wurde die Erfassung der chemischen Qualität des Perkolationswassers und der Vergleich mit der Chemie des regional vorkommenden Grundwassers unmöglich. Die Applikation von Aschedüngern hatte keinen Effekt auf das Bodenwasser in 40 cm Tiefe. Die Applikation von organischen Düngemitteln erhöhte die Photosyntheseleistung der Pflanzen und führte zur Erhöhung der Produktivität.

SCHLÜSSELWORTE: Flugasche, Klärschlammkompost, Pflanzenwachstum, Biomasse, Photosynthesleistung

INTRODUCTION

Ashes are an unavoidable waste resulting from the operation of the coal-fired electric generating plants. The fly ashes from hard coal constitute a fine-grained material dominated by the dust fraction (0.1–0.2 mm), characterized by a high alkalinity (pH 9-13) and the lack of organic substance and nitrogen. Huge amounts of those wastes have been disposed in landfills of a considerable area excluded from the agricultural and forestry use. Presently the furnace wastes are widely used in the construction and road industries as well as in the macro leveling (Goss, 2003; Koolen, 2000). It is also possible to use this waste product in the reclamation of the degraded land (Misior et al., 2003; Rethman et al., 2001). In order to improve the characteristics of the ashes as a reclaiming material other waste products abundant in organic matter and nutritious components, particularly the nitrogen, can be used as admixture. Such materials are: sewage sludge and composts made of these, furthermore bark, peat, straw, or the municipal greens waste may be also used. The value of the municipal sewage sludge is determined by the content of the organic matter, nitrogen, phosphorus and the trace elements (Baran et al., 1993; Krzywy and Wołoszyk, 1996). The application of the ashes with the addition of the organic waste in the land reclamation demands detailed studies determining their effect on the environment. The general objective of this project is to evaluate the quality and quantity of the water percolating through the reclaiming layers and the growth of grass mixtures sown on the reclaimed object. This work concentrates on the description of the beginning stages of the plant growth.

METHODS

The research has been conducted from 2003 at the Dolna Odra Power Plant in Nowe Czarnowo on an experimental model consisting of four lysimeters, each comprising an area of 35 m^2 (Fig.1). The lysimeters were filled with the 2.0 m thick layer of the reclaiming subsoil. The bottom stratum 1.6 m thick consists of the ash-slag, whereas the top one 0.4 m thick is a mixture of ash-slag and the organic waste. The experimental factors comprise:

- application of the filling: (A) consisting of the ash-slag with the added mineral fertilizers NPK (60-70-70 kg/ha -1) and (B) consisting of the sole ash-slag;
- application of the top layer: (1) mixture of a peat with slag at the proportion 1:3 and (2) mixture of coniferous bark, the loose sand, compost produced by the GWDA method, and compost from a fermented municipal sewage sludge with straw consisting of 70% sludge and 30% straw corresponding by dry weight, at the proportion 1:1:2:4.

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 108-114
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) *ISBN 3-900865-17-5*

The estimation of trace elements in the ash-slag and composts from sewage-sludge showed that the concentration did not exceed the norm of the Polish Ministry of Environment and the norms of the Polish Ministry of Agriculture concerning organic fertilizers and could be used for the ground reclamations.

The following mixture of grass species, i.e. perennial darnel var. Sakini - 35%, perennial darnel var. N1/94 - 15%, red fescue var. Pernille - 15%, red fescue var. Elanor - 30%, meadow bluegrass var. Balin - 5% was sown on the lysimeters. The sowing rate equaled 1 kg seeds to one lysimeter. The sowing took place on August 26, 2003. For plant analyses each lysimeter was divided into 4 plots.

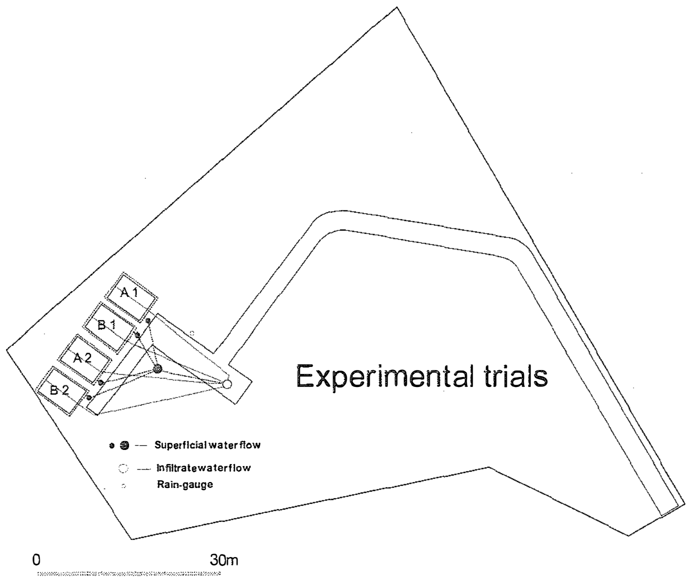


Fig. 1.: Scheme of experimental model design. – Abb. 1: Schema der Versuchsanordnung.

We have collected meteorological data, especially concerning rainfall; chemical composition of the underground water; quantity and quality of surface and infiltration water.

The grass seedlings growing on the lysimeters were measured for:

- chlorophyll contents with the SPAD-502 analyzer manufactured by Minolta, Japan in 25 specimens of darnel and fescue on each plot.
- gas exchange of plants (e.g. A - intensity of CO2 assimilation, E - intensity of transpiration, g_S - stomatal conductivity to H_2O, c_i - CO2 concentration (intracellular) with the LCA-4 gas analyzer manufactured by ADC, England, with a chamber equipped

with a light source of 1000 μmol·m^{-2}·s^{-1} intensity. These measurements were performed on 5 specimens of darnel.

- light transmission in the canopy was measured with the AccuPar ceptometer manufactured by Decagon, USA. 20 measurements were made on each plot.
- LAI (Leaf Area Index) was also measured because it is the most frequently used parameter of plant growth on the canopy level.

Prior to the harvest, 10 specimens of each species were collected and their length as well as the fresh and dry weight of the seedlings were determined. The grass was harvested on October 3 with an electric mower; the plants were cut at the height of 4 cm on each plot. The lysimeter was divided into four parts and on each the fresh and dry weight were estimated separately and next recalculated on the 1 m^2.

The results were elaborated by means of the one factor analysis of variance in a complete randomized design. Multiple comparisons of means were conducted according with a Duncan test at p=0.05, creating homogenous groups. The means in the tables denoted with the same letter in the same line do not differ significantly.

RESULTS

Due to the exceptionally high temperatures and a scarce rainfall in 2003 no percolation of the rain water through the reclaiming layers was noted hindering the analysis of the ash-slag and the organic waste components washing and also the effect of the sodding on the above process.

The yield of the biomass differed considerably due merely to the applied surface layer (Table 1). Both the fresh and dry weight of plants for the A2 and B2 variants (compost surface layer) were four times higher as compared to the A1 and B1 variants (ash and peat overlay). The development of the assimilation surface of the canopy (LAI) was subject to the quantitative changes due to the applied surface layers similarily to changes in the biomass accumulation. At this stage of plant growth no fertilization effect of the bottom ash-slag layer treatment with mineral fertilizers was noted.

Tab. 1: Fresh and dry weight of plants and the LAI according to the reclaiming variant.

Tab. 1: Frisch- und Trockengewicht der Pflanzen und Blattflächenindex der Versuchsvarianten

Feature	Variant				Mean
	A1	B1	A2	B2	
Yield of fresh weight [g / m^2]	225 *b*	246 *b*	1050 *a*	1035 *a*	639
Yield of dry weight [g / m^2]	38.1 *b*	35.6 *b*	147.4 *a*	139.4 *a*	90.3
LAI	0.99 *b*	1.01 *b*	4.33 *a*	4.71 *a*	2.76

The establishment of the grass sod is the resultant of the growth of individual seedlings and of the respective species as well as the competitive inter- and intraspecies relations. The growth parameters of the individual seedlings indicate better conditions of growth in the lysimeters filled with the compost surface layers as compared to the layers (Table 2). Only red fescue did not react considerably to the kind of the applied surface layer.

The chlorophyll content in the leaves is most frequently correlated with the nitrogen content as the majority of nitrogen in the assimilative parts of a plant is connected with its photosynthetic complex and the measurements with the chlorophyll meter may be used for the estimation of fertilization demands of plants (Peltonen et al., 1985). A higher chlorophyll content was noted in the leaves of the perennial darnel and the meadow bluegrass in the variants with the compost surface layer (Table 3). A similar regularity was also noted in the perennial darnel while measuring the activity of the gas exchange (Table 4).

Tab. 2: Biometric parameters of the individual seedlings of the grass species according to the reclaiming variant.

Tab. 2: Statistische Parameter der Grassämlinge der Versuchsvarianten.

Feature	Species	Variant				Mean
		A1	B1	A2	B2	
Fresh weight [mg]	perennial darnel	131 *b*	134 *b*	221 *a*	216 *a*	176
	red fescue	16.0 *c*	20.5 *b*	21.5 *ab*	23.5 *a*	20.4
	meadow blugrass	166 *b*	155 *b*	235 *a*	226 *a*	178
Dry weight [mg]	perennial darnel	19.5 *b*	20.5 *b*	32.0 *a*	31.0 *a*	25.8
	red fescue	2.5 *b*	3.5 *ab*	4.0 *ab*	4.5 *a*	3.63
	meadow blugrass	29.5 *b*	28.0 *b*	43.0 *a*	41.0 *a*	32.3
Length [cm]	perennial darnel	16.8 *b*	16.3 *b*	25.0 *a*	26.0 *a*	21.0
	red fescue	10.5 *b*	11.8 *b*	16.5 *a*	14.8 *a*	13.4
	meadow blugrass	6.50 *bc*	5.25 *c*	8.50 *a*	8.00 *ab*	7.06

Tab. 3: Chlorophyll content (SPAD units) in the leaves of 2 species of grass according to the reclaiming variant.

Tab. 3: Chlorophyllgehalt in den Blättern von zwei Grasarten der Versuchsvarianten.

Species	Variant				Mean
	A1	B1	A2	B2	
Perennial darnel	26.0 *b*	24.2 *b*	33.3 *a*	33.5 *a*	29.2
Meadow blugrass	33.2 *b*	31.8 *b*	40.7 *a*	40.4 *a*	36.0

Tab. 4: Parameters of the gas exchange (A-assimilation rate, E- transpiration rate, g_s- stomatal conductance to H_2O, c_i- intercellular CO_2 concentration) of the perennial darnel plants according to the reclaiming.

Tab. 4: Parameter des Gasaustausches (A-Assimilationsrate, E-Transpirationsrate, g_s- stomatäre Leitfähigkeit für H_2O, c_i- interzelluläre CO_2 Konzentration) des mehrjährigen Pflanzen der verschiedenen Behandlungen.

Feature	Variant				Mean
	A1	B1	A2	B2	
A [$\mu mol\ m^{-2}\ s^{-1}$]	7.52 *bc*	7.02 *c*	8.23 *ab*	8.56 *a*	7.83
E [$mmol\ m^{-2}\ s^{-1}$]	2.36 *b*	2.22 *b*	2.75 *a*	2.84 *a*	2.54
g_S [$mol\ m^{-2}\ s^{-1}$]	1.56 *c*	1.47 *c*	1.78 *b*	2.25 *a*	1.77
c_i [$\mu mol\ mol^{-1}$]	315 *a*	308 *a*	326 *a*	341 *a*	322

CONCLUSIONS

High temperatures and scarce rainfall during the vegetation period in 2003 resulted in no water percolation through the reclaiming layers in the lysimeter. This hindered the estimation of the chemical content of the percolates and the comparison of these percolates with the content of the underground water naturally existent in the given area.

At the present development of grass plants no effect of mineral fertilization of the ash-slag layer at the depth of 0,4 m below the soil surface could be observed. The factor which affected the growth of some grass species was the kind of the applied surface mixture. The application of the fertile surface layer based on sludge compost caused an increase of green mass yield as compared to the ash-peat surface layer. Uneven sprouting and a decreased number of plants in the variants with the ash surface layer resulted in a considerably lower biomass yield per unit area as could be expected from the differences in weight of individual seedlings. This observation confirmed our earlier study under laboratory conditions with the triticale seedlings (Stankowski and Cyran, 1996). The results are preliminarily and the experiment will be conducted for several years.

LITERATURE

Baran S., Flis -Bujak M., Turski R., Żukowska G., 1993: Przemiany substancji organicznej w glebie lekkiej użyźnionej osadem ściekowym (The conversion of organic substances in the soil fertllized of sewage-sludge). Zesz. Probl. Post. Nauk. Rol. **409**: 243-250.

Goss D., 2003: Produkty spalania węgla w Stanach Zjednoczonych - szanse i wyzwania (The by-products from coal combusition in USA- the chances and challenges). Popioły z energetyki. Mat. Konf. Nauk Warszawa 14-17 październik 2003: 9-30.

Koolen A. J., 2000: Applicability of waste materials (a.o. compost, mine stone, gypsum) to vegetated civil surfaces. Folia Univ. Agric. Stetin. **(81)**: 45-54.

Krzywy E., Wołoszyk Cz., 1996: Charakterystyka chemiczna i możliwości wykorzystania do produkcji kompostów osadów ściekowych z miejskich oczyszczalni (The chemical composition and possibilities to use of the sewage-sludge kompost). Folia Univ. Agric. Stetin. **(62)**: 265-271.

Misior M., Lozański M., Truszkowska K. 2003: Rekultywacje i makroniwelacje - alternatywa dla unieszkodliwiania odpadów poprzez składowanie (Reclamation and micro leveling- the alternative way to the storage). Popioły z energetyki. Mat. Konf. Nauk Warszawa 14-17 październik 2003: 201-222.

Peltonen J., Virtanen A., Haggren E., 1995: Using a chlorophyll meter to optimize nitrogen fertilizer application for intensively-managed small-grain cereals. J. Agron. Crop Scie. **174**: 309-318.

Rethman N., Kruger R. A., du Toit E., Ramagadza E., Truter W., Reynolds K., 2001: The use of fly ash and biosolids to amelirate soils, revegetate disturbed areas and improve plant productivity. Proc. 14th International Symposium on Management and Use of Coal Combusition Products (CCPs), V. 1, EPRI, Palo Alto, CA.

Stankowski S., Cyran A., 1996: The effect of pit coal ashes on seed germination, growth and chemical composition of winter triticale plants. Plant Breeding and Seed Science **40 (1-2)**: 173-176.

WASSERQUALITÄT IN ZWEI BEWALDETEN EINZUGSGEBIETEN MIT UNTERSCHIEDLICHER DEPOSITIONSBELASTUNG – LANGFRISTIGE VERÄNDERUNGEN UND REAKTION AUF KALKUNG

WATER QUALITY IN TWO FORESTED CATCHMENTS WITH CONTRASTING LEVELS OF ATMOSPHERIC INPUT - LONG-TERM CHANGES AND REACTIONS ON SOIL LIMING

Martin ARMBRUSTER, Mengistu ABIY und Karl-Heinz FEGER

Institut für Bodenkunde und Standortslehre, Technische Universität Dresden

ZUSAMMENFASSUNG:

Im Beitrag werden die biogeochemischen Flüsse von zwei mit Fichten bestockten Kleineinzugsgebieten in Deutschland dargestellt. Das Einzugsgebiet „Schluchsee" (Schwarzwald) ist durch eine relativ geringe Depositionsbelastung gekennzeichnet, während das Einzugsgebiet „Rotherdbach" (Osterzgebirge) hohe Stoffeinträge erhielt. Als Reaktion rückläufiger S-Deposition sind die SO_4^{2-}-Konzentrationen im Sickerwasser und Bachwasser ebenfalls rückläufig. Im Gebiet ist bei nachlassender Protonen und S-Deposition eine Reversibilität der Gewässerversauerung erkennbar. Die N-Eintragsraten sind dagegen in beiden Gebieten auf ähnlichem Niveau geblieben. In Schluchsee blieb die NO_3^--Konzentration im Bachwasser nahezu konstant, während in Rotherdbach ein deutlicher Rückgang beobachtet wurde. Die Säureneutralisationskapazität stieg nur im derzeit permanent versauerten Bachwasser des Rotherdbach an. In Schluchsee wurde keine Veränderung festgestellt. Schlüsselfaktor für die Ausprägung der Reversibilität von Gewässerversauerung sind offensichtlich Art, Höhe und Verteilung der im Ökosystem gespeicherten S-Vorräte. Beide Gebiete wurden mit dolomitischem Gesteinsmehl behandelt (Schluchsee: 4 t ha^{-1}, Parallel-Einzugsgebiet 1990; Rotherdbach: 4,5 t ha^{-1} 2001). In unseren Untersuchungen wurden nur geringe Effekte der Kalkung auf Gewässerqualität, sowohl was der den Gewässerversauerungszustand als auch die potentielle Mobilisierung von Nitrat oder Sulfat betrifft.

STICHWÖRTER: atmosphärische Deposition; bewaldete Einzugsgebiete; Reversibilität der Gewässerversauerung; Bachwasser; Kalkung

ABSTRACT:

The biogeochemical input-output fluxes of two forested catchments in Germany with contrasting levels of atmospheric deposition were investigated. The catchment 'Schluchsee' (Black Forest, SW Germany) is characterized by relatively low atmospheric inputs whereas 'Rotherdbach' (Ore Mountains, E Germany) received significant amounts of acid deposition until recent years. In response to reduced S deposition, soil solution and streamwater SO_4^{2-} concentrations decreased significantly. The level of N deposition was more or less constant at both sites. At Schluchsee, NO_3^- concentrations in streamwater remained more or less unchanged, whereas a decrease

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 115-139
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

at Rotherdbach was observed. Streamwater ANC increased only in the permanently acidified Rotherdbach. No change of ANC was observed in the Schluchsee stream. It appears that the key factor controlling the recovery from surface water acidification was the type, amount and distribution of stored S pools in the ecosystem. Both catchments received a treatment of soil liming with dolomite (Schluchsee: 4 t ha^{-1}, adjacent catchment, 1990; Rotherdbach: 4.5 t ha^{-1}, 2001). In our experiments, effects of liming on water quality were small, both with regard to a mitigation of the acidification status and a potential mobilization of nitrate or sulfate.

KEYWORDS:

Atmospheric deposition; forested catchments; recovery from acidification; streamwater; soil liming.

EINLEITUNG

In den zurückliegenden zwei Jahrzehnten wurden rückläufige Tendenzen der Stoffeinträge in Waldökosysteme für SO_4^{2-} und H^+, aber auch die Kationen K^+, Ca^{2+} und Mg^{2+} festgestellt (Tarrasón und Schaug, 1999; Stoddard et al., 1999; Alewell et al., 2000, 2001). Der positive Effekt des Rückgangs der SO_2-Emissionen (Rückgang der SO_4^{2-}- und H^+-Deposition) kann dabei jedoch durch gleichzeitigen Rückgang der neutralisierenden basischen Stäube z.T. wieder kompensiert werden. Die vielerorts erhöhten N-Eintragsraten sind dagegen auf gleichbleibendem Niveau geblieben. Die Auswirkungen solcher Stoffeintragsänderungen auf die Zusammensetzung von Bodensicker- und Bachwasser sowie die mögliche Erholung von Böden und Waldökosystemen werden derzeit kontrovers diskutiert. Ein Schlüsselprozess der Reversibilität von Versauerungsprozessen ist die Höhe und Ausprägung der S-Speicherung in Böden. Vereinfacht dargestellt reagieren Ökosysteme mit geringen Mengen gespeichertem SO_4^{2-} sehr schnell mit einer Zunahme der Säureneutralisationskapazität, was als Reversibilität von Versauerung gedeutet werden kann. Sind dagegen große Mengen an SO_4^{2-} im Boden gespeichert, wird bei Rückgang der S-Einträge im Boden gespeichertes SO_4^{2-} wieder freigesetzt. Eine Reversibilität der eingetretenen Gewässerversauerung tritt in diesen Systemen daher nur mit beträchtlicher zeitlicher Verzögerung auf (Alewell, 1995).

Vor dem Hintergrund anhaltend hoher N-Einträge bei gleichzeitig rückläufigen Säureeinträgen kommt dem Nitrat in Zukunft eine größere Bedeutung für die Versauerung zu. Daneben ist bei der zukünftig zu erwartenden N-Eintragssituation (stagnierend auf vergleichsweise hohen Niveau) zunehmend auch eine nachlassende N-Retentionskapazität („N-Sättigung") der Waldökosysteme zu erwarten (Feger, 1993; Feger, 1997/98; Moldan und Wright, 1998).

Großflächige Kalkungen haben in der forstlichen Praxis in den letzten Jahren weite Verbreitung gefunden. Dabei überlagern sich häufig ganz unterschiedliche Motivationen: Bodenmelioration, Säurekompensation, Düngung, Boden- bzw. Grundwasserschutz (Leube, 2000; Feger, 1996). Ein häufig genanntes Ziel von Kalkungsmaßnahmen besteht somit auch darin, das Quell- und Grundwasser vor Schwermetall-, Aluminium- und Säureeinträgen zu schützen. Diesen angestrebten Zielen stehen allerdings eine Reihe möglicher Risiken gegenüber.

Die Ziele der vorliegenden Untersuchung sind daher: (1) Vergleich der biogeochemischen Flüsse zweier Waldökosysteme mit unterschiedlicher Depositionsbelastung, (2) Identifikation und Berechnung der Auswirkungen veränderter Stoffeinträge auf Bodenlösung und Gebietsaustrag und (3) die Bewertung der Wirksamkeit von Waldbodenkalkungen im Hinblick auf den Gewässerzustand.

MATERIAL UND METHODEN

Gebietsbeschreibungen

Für die Fragestellung wurden zwei bewaldete Einzugsgebiete im Schwarzwald und Osterzgebirge heran gezogen (Tab. 1, Abb. 1). Die beiden Untersuchungsobjekte zeichnen sich durch vergleichbare Größe, Ausgangsgesteine, Bestockung und Böden aus. Hingegen unterscheiden sie sich sehr stark hinsichtlich ihrer atmosphärischen Deposition.

Das Einzugsgebiet Schluchsee befindet sich in der hochmontanen Stufe des Südschwarzwaldes. Im gesamten Einzugsgebiet stockt ein ca. 55jähriger Fichtenreinbestand. Das Einzugsgebiet Rotherdbach liegt im Übergangsbereich zwischen den mittleren und höheren Lagen des Osterzgebirges. Es ist zu ca. 83 % mit einem alten Fichtenreinbestand bestockt. Etwa 17 % der Einzugsgebietsfläche besteht aus einer ca. 15jährigen Fichtenaufforstung. Seit den 1970er Jahren zeigten sich in den Kammlagen des Osterzgebirges starke SO_2-immissionsbedingte Waldschäden mit großflächigen Absterbeerscheinungen. Aufgrund der Höhenlage trat im

Untersuchungsgebiet jedoch kein flächiges Absterben auf. Klimatisch ist das Rotherdbachgebiet wie das Schluchseegebiet als kühl und perhumid zu charakterisieren. Allerdings beträgt der mittlere Jahresniederschlag im Rotherdbach nur etwa die Hälfte des in Schluchsee gemessenen Wertes.

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 115-139
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

Tab. 1: Kenndaten der beiden Einzugsgebiete.

Table 1: Characteristics of the studied catchments.

	Schluchsee	Rotherdbach
Untersuchungszeitraum [a]	1988 – 1998	1994/95 – 2003 [b]
Lage	47° 49' N; 8° 06' E	50° 47' N; 13° 43' E
Einzugsgebietsfläche [ha]	11,0	9,4
Höhenlage [m ü. NN]	1150 – 1253	694 – 750
mittl. Gefälle [%]	21,9	16,7
Exposition	ENE	SE
mittl. Niederschlag [mm]	1867	989 [c]
mittl. Abfluss [mm]	1381	590 [c]
mittl. Lufttemperatur [°C]	4,5	5,5
Vegetation	Fichte 55 a (100%)	Fichte 90 a (83%); Fichte 15 a (17%)
Böden	Eisenhumuspodsole; (Braunerde-Podsole)	Eisenhumuspodsole; Braunerde-Podsole
Grundgestein	Granit	Quarzporphyr

[a] hydrologische Jahre (Nov. – Okt.)
[b] zeitreihenanalytische Untersuchungen: 1994-1999; Kalkungseffekte: 2000-2003
[c] Zeitraum 1995 – 1999

Beide Einzugsgebiete werden durch perennierende Quellbäche entwässert (Abb. 1). Den geologischen Untergrund bildet in ***Schluchsee*** der extrem basenarme Bärhaldegranit. Es dominieren lehmig-sandige Böden mit einem hohen Skelettanteil von bis zu 60 % (überwiegend Feinskelett). Als Böden haben sich gut durchlässige, saure und extrem basenarme Eisenhumuspodsole entwickelt (Zöttl et al., 1977; Armbruster, 1998). Das Grundgestein im Gebiet des ***Rotherdbach*** bildet der Teplitzer Quarzporphyr (Nebe et al., 1998). Dieser ist - mit Ausnahme etwas höherer Ca- und Mg-Gehalte - in der Elementzusammensetzung dem Ausgangsgestein in Schluchsee vergleichbar. Die Böden, sandige Lehme bis Lehme, haben in der Basisfolge bis zu 70 % Skelettanteil. Im Gegensatz zum Schluchseegebiet ist die hydraulische Leitfähigkeit der Böden deutlich geringer, wodurch laterale Fließwege an Bedeutung zunehmen. Die Bodentypen sind dem Schluchseegebiet vergleichbar. Allerdings sind Basensättigung, Kationenaustauschkapazität und S_{ges}-Gehalte im Vergleich zu Schluchsee höher (Abiy, 1998). Weiterführende Gebietsbeschreibungen geben Brahmer (1990), Armbruster (1998) sowie Abiy (1998).

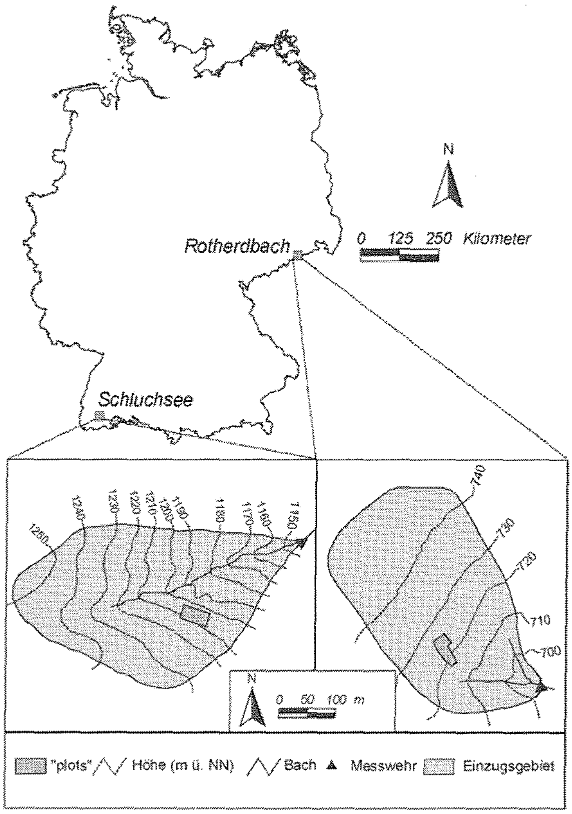


Abb. 1: Lage der beiden Untersuchungsgebiete in Deutschland.
Fig. 1: Location of the two catchments in Germany.

Methoden

Probenahmen und Analysen

Die Beprobung in den beiden Einzugsgebieten erfolgte seit 1987 (Schluchsee) beziehungsweise 1993 (Rotherdbach). Der Freilandniederschlag zur Ermittlung des Eintrags oberhalb des Kronendachs wurde wöchentlich auf jeweils einer benachbarten Freifläche gesammelt. Die Kronentraufe (Bestandsniederschlag) wurde in repräsentativen Teilflächen innerhalb des Einzugsgebietes („plots"; Abb. 1) ebenfalls wöchentlich aufgefangen. Die Niederschlagsproben wurden zur Analyse volumengerecht zu Monatsmischproben vereinigt. In den Bestandesmessflächen wurde in wöchentlichem bis 14tägigem (Schluchsee) bzw. monatlichem Abstand (Rotherdbach) Bodensickerwasser mittels Unterdruck-Lysimetern in Platten- bzw. Kerzenbauweise unterhalb der Humusauflage und in verschiedenen Tiefen des Mineralbodens gewonnen. Der Gebietsaustrag wurde in beiden Einzugsgebieten an THOMPSON-Messwehren bestimmt. Die Beprobung des Bachwassers erfolgte in Schluchsee in wöchentlichen und im Rotherdbach monatlichen Abständen.

An allen Wasserproben wurden die Hauptkationen (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, Al_{ges}, Mn_{ges}, Fe_{ges}) und -anionen (Cl^-, NO_3^- und SO_4^{2-}) sowie pH-Wert und elektrische Leitfähigkeit bestimmt. Die Säureneutralisationskapazität (SNK) wurde rechnerisch aus der Ionenbilanz ermittelt (Reuss und Johnson, 1986; van Miegroet, 1994). Detaillierte Angaben zu den analytischen Methoden sind in Feger (1993) für Schluchsee sowie Langusch (1995) für Rotherdbach zu finden.

Kalkungsmaßnahmen

In ***Schluchsee*** erfolgte am 15.10.1990 die Kalkung eines parallel angelegten Einzugsgebietes (Raspe et al., 1998). Das ursprüngliche Einzugsgebiet blieb als Kontrolle unbehandelt. Beim applizierten Material handelte es sich um einen handelsüblichen Dolomitkalk in Granulatform. Die Aufwandmenge entspricht einer praxisüblichen Dosierung von 4 t ha^{-1}. Die Ausbringung des Dolomitkalkes erfolgte manuell, um eine Kontamination des unmittelbar angrenzenden Kontrollgebietes zu vermeiden. Durch Anlage eines 0,25-ha-Gitterrasters wurde eine möglichst gleichmäßige Ausbringung realisiert.

Am 10.7.2001 erfolgte die Kalkung des Einzugsgebietes ***Rotherdbach*** durch praxisübliche Helikopterausbringung in einer Aufwandmenge von 4,5 t ha^{-1} (dolomitischer Kalk 0-3 mm aufgemahlen). Eine Dauerbeobachtungsfläche innerhalb des Einzugsgebietes wurde dabei von der Kalkung als Kontrollfläche ausgespart. Zur Überprüfung der gleichmäßigen Ausbringung und der geforderten Aussparung der Kontrollfläche wurden an einem bestehenden Bodenprobenraster die auf die Bodenoberfläche gelangenden Kalkmengen erfasst.

Berechnung von Stoffflüssen

Die Einträge mit dem Freiland- bzw. Bestandesniederschlag wurden durch Multiplikation der Stoffkonzentrationen und der Niederschlagsmengen der Sammelzeiträume und Aufsummierung über jährliche Untersuchungszeiträume berechnet. Die Gesamtdeposition wurde nach dem Ansatz von Ulrich (1983, 1991) bestimmt, wobei Erweiterungen für die Untersuchungsgebiete in Brahmer (1990), Armbruster (1998) und Abiy (1998) beschrieben sind. Die Berechnung des Gebietsaustrags mit dem Bachwasser erfolgte in Schluchsee mit der „period-weighted-sample“-

Methode (Likens et al., 1977). In Rotherdbach wurde der jährliche Gebietsaustrag dagegen durch Multiplikation der durchschnittlichen Elementkonzentration eines Jahres mit der Jahresabflusssumme berechnet. Die so bestimmten Elementausträge unterscheiden sich dabei in Rotherdbach nicht von den über die „period-weighted-sample"-Methode berechneten (Abiy, 1998).

Zeitreihenanalysen

In der vorliegenden Untersuchung wurde ein additives Zeitreihenmodell zur Beschreibung der Zeitreihen von Deposition, Bodenlösung und Bachwasser verwendet. Die Bestimmung der Trendkomponente erfolge über ein saisonales, multiples Regressionsmodell (Flieger und Toutenburg, 1995). Neben saisonaler Komponente und Trendkomponente wurde eine wassermengenabhängige Komponente eingeführt. Für Rotherdbach standen keine Sickerwassermengen zu Verfügung, weshalb für das Bodensickerwasser im Zeitreihenmodell nur die saisonale Komponente und die Trendkomponente berücksichtigt werden. Die zeitliche Auflösung der Zeitreihenanalyse wurde nach dem Abstand der jeweiligen Probenahmen gewählt. An beiden Standorten wurden daher monatliche Einträge mit dem Freiland- und Bestandesniederschlag untersucht. Im Bodensickerwasser und Bachwasser wurden dagegen die Zeitreihen der Konzentrationen heran gezogen. Die zeitliche Auflösung der Analyse war in Schluchsee 14tägig für das Bodensickerwasser und wöchentlich für das Bachwasser. Bei Rotherdbach wurden monatliche Konzentrationswerte von Bodensickerwasser und Bachwasser untersucht. Die Normalverteilung der Regressionsresiduen wurde graphisch durch den Vergleich mit der Normalverteilung überprüft. Zur Überprüfung der Residuen auf Autokorrelation wurde der Durbin-Watson-Koeffizient berechnet. Die Zeitreihenanalyse erfolgte mit dem Statistikpaket SPSS 10.0. Weiterführende Angaben zu den verwendeten Rechenverfahren und -programmen finden sich in Armbruster (1998).

ERGEBNISSE

Wasser- und Stoffbilanzen

In Tab. 2 sind die durchschnittlichen Wasser- und Elementflüsse der beiden Untersuchungsgebiete zusammengestellt. Die Einträge mit dem Freilandniederschlag (NF) sind in beiden Gebieten für die meisten Elemente vergleichbar. Geringere Na^{+}- und Cl^{-}-Einträge im Freiland in Rotherdbach sind typisch für das meerfernere Gebiet im Erzgebirge. Dagegen sind die N_{ges}- und SO_4^{2-}-Einträge in Rotherdbach im Freilandniederschlag etwas erhöht. Die Einträge mit dem Bestandesniederschlag und die berechnete Gesamtdeposition sind in Rotherdbach dagegen deutlich höher als in Schluchsee. In Schluchsee spielt die trockene Deposition (GDP – NF) mit 10 bis 20 % Anteil an der Gesamtdeposition nur eine untergeordnete Rolle. In Rotherdbach ist dagegen der überwiegende Anteil der H^{+}- und SO_4^{2-}-Gesamtdeposition der trockenen Deposition zuzuordnen. Für die weiteren Elemente beträgt der Anteil der trockenen Deposition etwa 50 %. Die Elementflüsse des konservativen Elements Cl sind in Schluchsee ausgeglichen. Dies unterstreicht die Eignung des Einzugsgebietes für die Aufstellung von Wasser- und Stoffbilanzen. Hingegen ist für Rotherdbach die Cl^{-}-Bilanz negativ, was durch die winterliche Ausbringung von Streusalz auf einer Durchgangsstraße im oberen Teil des Einzugsgebietes erklärt wird (Abiy, 1998).

Beide Untersuchungsgebiete zeigen eine Netto-Freisetzung von SO_4^{2-}. Der durchschnittliche Gebietsaustrag mit dem Bachwasser ist in beiden Gebieten etwa doppelt so groß wie der Gebietseintrag (Gesamtdeposition, Tab. 3.1). Der Netto S-Austrag (berechnet aus Gebietsaustrag minus Gesamtdeposition) beträgt 8 kg ha^{-1} a^{-1} in Schluchsee und 34 kg ha^{-1} a^{-1} in Rotherdbach. Stickstoff wird dagegen in beiden Gebieten im Ökosystem zurückgehalten (Schluchsee: 4 kg ha^{-1} a^{-1} N; Rotherdbach 15 kg ha^{-1} a^{-1} N). Als Folge der höheren Gebietsausträge der Anionen Cl^{-}, NO_3^{-} und SO_4^{2-} sind in Rotherdbach auch deutlich höhere Kationenausträge (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}) und Al_{ges}-Austräge vorhanden.

Tab. 2: Durchschnittliche Wasser- und Elementflüsse mit Freilandniederschlag (NF) Bestandesniederschlag (NB), und Gebietsaustrag (GA) sowie berechnete Gesamtdeposition (GDP). Alle Elementflüsse in kg ha^{-1} a^{-1}.

Table 2: Average values of water and element fluxes with bulk deposition (NF), throughfall (NB), total deposition (GDP) and stream output (GA). All fluxes in kg ha^{-1} yr^{-1}.

	Schluchsee (1988 – 1998)				Roterdbach (1995 – 1999)			
	NF	**NB**	**GDP**	**GA**	**NF**	**NB**	**GDP**	**GA**
mm H_2O	1867	1543		1381	989	803		563
H^+	0,34	0,26	0,43	0,01	0,32	0,91	1,43	0,42
Na^+	4,1	4,7	4,7	21,2	2,3	4,6	4,6	26,6
K^+	2,1	13,3	2,4	7,8	1,0	14,6	2,0	13,3
Ca^{2+}	3,9	6,1	4,6	13,6	3,5	13,6	7,0	41,3
Mg^{2+}	0,7	1,1	0,8	2,2	1,3	4,0	2,6	14,5
NH_4^+-N	5,0	3,6	5,7	0,1	6,7	8,7	13,4	0,2
NO_3^--N	4,5	5,4	5,5	6,9	6,4	11,4	12,8	10,9
N_{ges} [a]	9,5	8,9	11,2	7,0	13,1	20,1	26,2	11,1
SO_4^{2-}-S [b]	6,8	8,4	8,3	16,3	10,7	34,0	34,0	68,1
Cl^-	8,4	9,1	9,0	9,4	6,1	11,7	12,2	55,9
Al_{ges}	0,16	0,25	0,20	3,3	0,26	0,98	0,52	14,9
Mn_{ges}	0,06	0,41	0,07	0,23	0,05	0,35	0,10	1,40
Fe_{ges}	0,10	0,14	0,12	0,11	0,14	0,47	0,28	0,41
DOC	21,4	57,0		18,9				26,8

[a] $N_{tot} = NH_4^+$-N + NO_3^--N
[b] Rotherdbach S_{ges} (SO_4^{2-}-S + S_{org})

Zeitliche Entwicklungen

Deposition

In beiden Untersuchungsgebieten zeigen sich signifikante Rückgänge der SO_4^{2-}-Einträge im Freiland- und Bestandesniederschlag (Tab. 3, Abb. 2). Exemplarisch sind in Abb. 3 die Ergebnisse des Zeitreihenmodells für SO_4^{2-} in Rotherdbach dargestellt. Die über das Modell bestimmten jährlichen Rückgänge an SO_4^{2-} sind in Rotherdbach etwa 10fach höher als in Schluchsee. Die gemessenen S-Einträge mit dem Bestandesniederschlag sind im ***Rotherdbach*** im Untersuchungszeitraum von 46 kg ha^{-1} a^{-1} (1994) auf 23 kg ha^{-1} a^{-1} (1999) zurückgegangen (Abb. 2). Die Aufsummierung der jährlichen Rückgänge des Zeitreihenmodells (2,6 kg ha^{-1} a^{-1}) über den 6jährigen Untersuchungszeitraum ergibt dagegen eine Abnahme um 16 kg ha^{-1}. Aufgrund der niedrigeren Eintragssituation in ***Schluchsee*** fällt hier der Rückgang deutlich geringer aus. Die Messwerte sind von 12 kg ha^{-1} a^{-1} S-Eintrag im Jahr 1988 auf 5,6 kg S ha^{-1} a^{-1} im Jahr 1998 gesunken (Abb. 2).

Tab. 3: Ergebnisse der Zeitreihenanalyse im Freilandniederschlag und Bestandesniederschlag der beiden Untersuchungsgebiete. Alle Trendangaben in g ha^{-1} a^{-1}.

Table 3: Results of time series analyses in bulk deposition (Freiland) and throughfall (Bestand) of study sites. All numbers are annual trends in g ha^{-1} yr^{-1}.

	Schluchsee (1988-1998)						Rotherdbach (1994-1999)					
	Freiland			Bestand			Freiland			Bestand		
	Trend	P	r^2	**Trend**	p	r^2	**Trend**	p	r^2	**Trend**	p	r^2
H^+		ns b	0,53	**-5**	*	0,49	**-37**	**	0,19	**-116**	***	0,44
Ca^{2+}	**-82**	**	0,29	**-132**	**	0,37	**-181**	**	0,29	**-455**	*	0,32
Mg^{2+}	**-16**	***	0,53	**-18**	**	0,40		ns b	0,19		ns b	0,38
SO_4^{2-}-S	**-88**	*	0,46	**-281**	***	0,50	**-983**	**	0,65	**-2621**	**	0,50
N_{ges} a	**-103**	*	0,61	**-166**	**	0,46	**-54**	**	0,54		ns b	0,30

* p < 0,05; ** p < 0,01; *** p < 0,001
[a] $N_{ges} = NH_4^+$-N + NO_3^--N
b ns = nicht signifikant

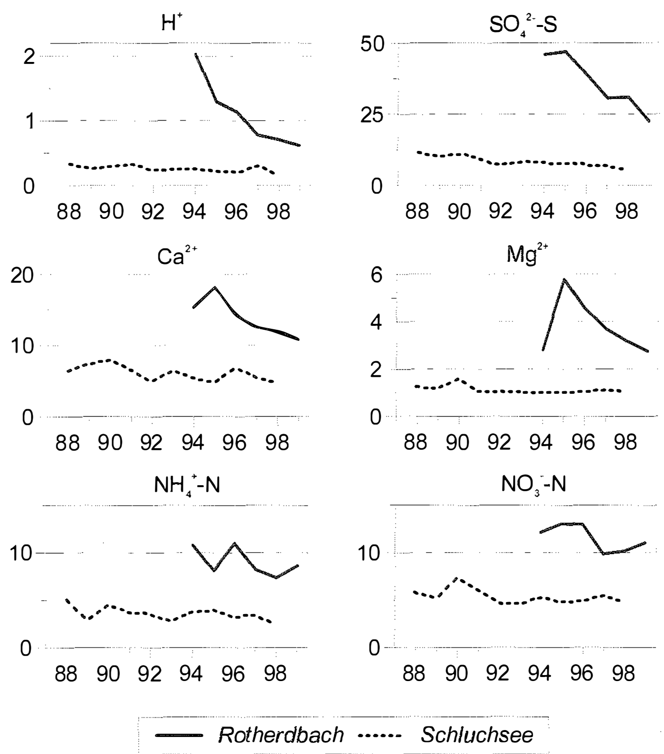


Abb. 2: Zeitliche Entwicklung der Einträge mit dem Bestandesniederschlag (kg ha^{-1} a^{-1}) der beiden Untersuchungsgebiete. Auf der X-Achse sind hydrologische Jahre (Nov. – Okt.) angegeben.

Fig. 2: Temporal development of throughfall deposition (kg ha^{-1} yr^{-1}) in both catchments. X-axis units represent hydrological years.

Die Aufsummierung der jährlichen Eintragsrückgangsraten aus der Zeitreihenanalyse ergibt für den 11jährigen Untersuchungszeitraum 3,1 kg ha^{-1} a^{-1}. In beiden Untersuchungsgebieten sind auch die N-Einträge im wohl FreilandniederschlagBestandsniederschlag zurückgegangen. Obwohl in Schluchsee ein geringeres N-Eintragsniveau vorhanden ist, sind hier die höheren Rückgänge zu verzeichnen. Im Bestandesniederschlag konnte dagegen nur in Schluchsee ein Eintragsrückgang bei N beobachtet werden. In Schluchsee wurden signifikante Abnahmen der Ca^{2+}- und Mg^{2+}-Einträge, sowohl im Freiland- als auch im Bestandesniederschlag ermittelt. Dabei zeigt die Mg^{2+}-Deposition aufgrund der niedrigen Eintragssituation nur eine vergleichsweise geringe Rückläufigkeit. Im Rotherdbachgebiet zeigen die Ca^{2+}-Einträge jährliche Abnahmeraten von 0,2 kg ha^{-1} a^{-1} im Freiland- und 0,46 kg ha^{-1} a^{-1} im Bestandesniederschlag. Für Mg^{2+} war in Rotherdbach kein signifikanter Trend nachweisbar.

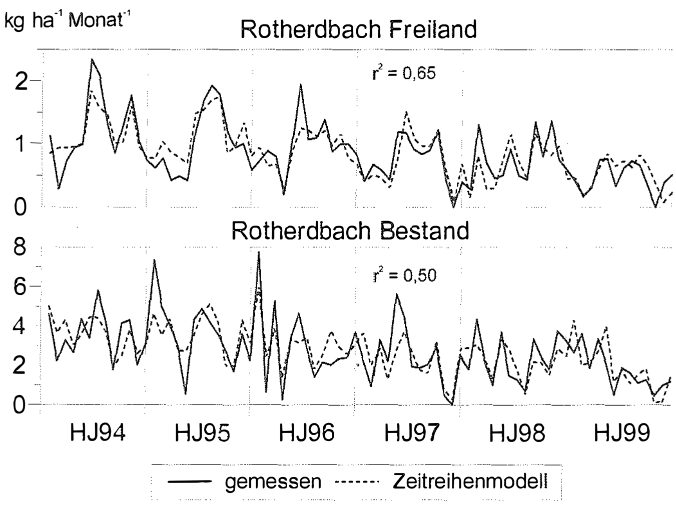


Abb. 3: Vergleich gemessener und mit dem Zeitreihenmodell vorhergesagter monatlicher SO_4^{2-}-Einträge mit Freiland- und Bestandesniederschlag des Einzugsgebietes ***Rotherdbach***.

Fig. 3: Comparison between measured and predicted (Zeitreihenmodell: time series model) values of monthly S-depositon (Freiland: bulk deposition; Bestand: throughfall) in the ***Rotherdbach*** catchment.

Sickerwasser und Bachwasser

Die Ergebnisse der Zeitreihenanalyse der Elementkonzentrationen im Bodensickerwasser und Bachwasser sind für das Einzugsgebiet ***Schluchsee*** in Tab. 4 zusammengestellt. Abb. 4 zeigt zusätzlich den Vergleich der aktuellen Werte mit den Prognosen des Zeitreihenmodells (exemplarisch für SO_4^{2-}). Der Rückgang der S-Einträge hat im Sickerwasser und Bachwasser zu einem Rückgang der SO_4^{2-}-Konzentrationen geführt. Dabei ist der berechnete Rückgang im Bachwasser mit 1 $\mu mol_c\ l^{-1}\ a^{-1}$ geringer als im Bodensickerwasser (2,4 – 2,7 $\mu mol_c\ l^{-1}\ a^{-1}$). Der zeitliche Trend für die „basischen" Kationen ist nicht für alle Kationen konsistent. Nur Ca^{2+} und Mg^{2+} zeigen signifikante Konzentrationsrückgänge in allen beobachteten Kompartimenten. Natrium zeigt dagegen einen signifikanten Anstieg im 30 cm Bodentiefe, während in den anderen Kompartimenten kein signifikanter Trend zu beobachten ist. Wird die Summe der „basischen" Kationen (ΣBC) betrachtet, zeigt sich eine Abnahme in allen Kompartimenten. Ebenfalls signifikant abnehmend sind die Konzentrationen von Al_{ges}, Mn_{ges} und die Summe der Anionen starker Säuren (ΣA). Als Folge der höheren Abnahme der Summe der Anionen starker Säuren (ΣA) im Vergleich zu der Summe „basischer" Kationen (ΣBC) im Bodensickerwasser steigt die SNK hier signifikant an. Im Bachwasser wurde dagegen kein signifikanter Rückgang der SNK festgestellt. Im tieferen Sickerwasser (80 cm) war die Anwendung des Zeitreihenmodells für die Ionen Na^+, K^+ und NO_3^- nicht signifikant. In der überwiegenden Anzahl der Fälle ist das Bestimmtheitsmaß r^2, das den Anteil der vom Modell beschriebenen Variabilität angibt, im Bachwasser höher als im Bodensickerwasser.

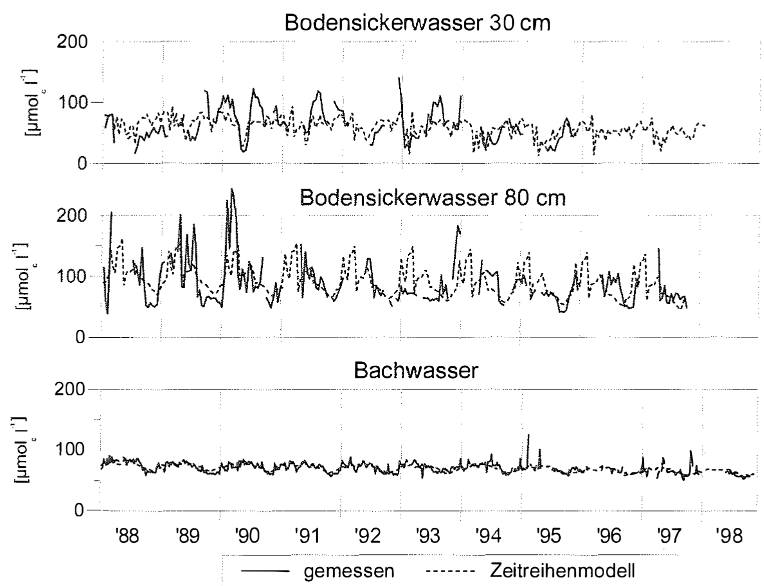


Abb. 4: Vergleich der gemessenen und mit dem Zeitreihenmodell vorhergesagten SO_4^{2-}-Konzentrationen im Bodensickerwasser und Bachwasser des Einzugsgebietes ***Schluchsee***.

Fig. 4: Comparison between measured and predicted (Zeitreihenmodell: time series model) values of SO_4^{2-} concentrations in the ***Schluchsee*** catchment.

Tab. 4: Ergebnisse der Zeitreihenanalyse der Elementkonzentrationen im Bodensickerwasser ausgewählter Bodentiefen und im Bachwasser des Einzugsgebietes ***Schluchsee***.

Table 4: Annual concentration trends in soil leachates (Bodensickerwasser) from selected soil depths and streamwater (Bachwasser) in the ***Schluchsee*** catchment.

1.11.87 - 31.10.98		**Bodensickerwasser [d]**						**Bachwasser**		
		30 cm Tiefe			**80 cm Tiefe**					
		Trend	**p**	**r^2**	**Trend**	**p**	**r^2**	**Trend**	**p**	**r^2**
H^+	($\mu mol_c\ l^{-1}$)	+2,9	***	0,23	+0,7	***	0,16	-0,04	**	0,80
NH_4^+	($\mu mol_c\ l^{-1}$)		ns	0,14		ns	0,14			[a]
Na^+	($\mu mol_c\ l^{-1}$)	+0,5	**	0,36			[a]		ns	0,70
K^+	($\mu mol_c\ l^{-1}$)	-0,6	***	0,10			[a]	+0,1	***	0,25
Ca^{2+}	($\mu mol_c\ l^{-1}$)	-1,0	***	0,50	-0,5	*	0,16	-1,0	***	0,25
Mg^{2+}	($\mu mol_c\ l^{-1}$)	-0,4	***	0,29	-0,9	***	0,48	-0,1	***	0,36
NO_3^-	($\mu mol_c\ l^{-1}$)	-1,4	***	0,33			[a]	+0,3	***	0,60
SO_4^{2-}	($\mu mol_c\ l^{-1}$)	-2,4	***	0,18	-2,7	***	0,29	-1,0	***	0,54
Cl^-	($\mu mol_c\ l^{-1}$)	+0,6	*	0,14		ns	0,25	+0,2	***	0,22
Al_{ges}	($\mu g\ l^{-1}$)	-25,1	***	0,30	-16,0	*	0,19	-3,6	***	0,81
Mn_{ges}	($\mu g\ l^{-1}$)	-1,6	***	0,45	-1,6	***	0,29	-0,5	***	0,76
Fe_{ges}	($\mu g\ l^{-1}$)		ns	0,32	-0,3	*	0,13	+0,2	***	0,24
DOC	($mg\ l^{-1}$)	+0,8	***	0,59	+0,3	***	0,39	+0,1	***	0,37
SNK	($\mu mol\ l^{-1}$)	+1,7	**	0,22	+2,4	***	0,33		ns	0,68
ΣBC [b]	($\mu mol_c\ l^{-1}$)	-1,6	***	0,27	-1,2	*	0,12	-0,7	***	0,51
ΣA [c]	($\mu mol_c\ l^{-1}$)	-2,2	***	0,19	-4,6	**	0,24	-0,3	*	0,65

*** $p < 0{,}001$; ** $p < 0{,}01$; * $p < 0{,}05$; ns nicht signifikant
[a] Modell nicht signifikant
[b] Summe „basischer" Kationen ($[Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}]$)
[c] Summe der Anionen starker Säuren ($[Cl^-] + [NO_3^-] + [SO_4^{2-}]$)
[d] Bodensickerwasser nur bis Oktober 1997 gemessen

Als Folge höherer Rückgänge in der Deposition ist auch die Abnahme der SO_4^{2-}-Konzentrationen im ***Rotherdbach*** stärker ausgeprägt (Tab. 5). Wiederum sind die Konzentrationsrückgänge im Sickerwasser (55 - 68 $\mu mol_c\ l^{-1}\ a^{-1}$) höher als im Bachwasser (41 $\mu mol_c\ l^{-1}\ a^{-1}$). Von den „basischen" Kationen weist im Rotherdbach nur das Ca^{2+} in allen Kompartimenten einen Konzentrationsrückgang auf. Folgerichtig ist für die Summe „basischer" Kationen (ΣBC) ebenfalls ein Rückgang erkennbar. Nur in 80 cm Bodentiefe, wo der geringste Ca^{2+}-Rückgang ermittelt wurde, ist kein signifikanter Trend der Summe „basischer" Kationen vorhanden. Die NO_3^-- und Al_{ges}-Konzentrationen zeigen ebenfalls einen signifikanten Rückgang. Im Rotherdbach-Einzugsgebiet zeigt die Säureneutralisationskapazität (SNK) in allen Sickerwassertiefen sowie im Bachwasser eine Zunahme. In Schluchsee wurde keine SNK-Zunahme im Bachwasser festgestellt. Im Vergleich zu Schluchsee sind in Rotherdbach die Fälle, bei denen eine signifikante Anwendung des Zeitreihenmodells nicht möglich war, höher.

Tab. 5: Ergebnisse der Zeitreihenanalyse der Elementkonzentrationen im Bodensickerwasser ausgewählter Bodentiefen und im Bachwasser des Einzugsgebietes ***Rotherdbach***.

Table 5: Annual concentration trends in soil leachates (Bodensickerwasser) from selected soil depths and streamwater (Bachwasser) in the ***Rotherdbach*** catchment.

1.11.94 - 31.10.99		**Bodensickerwasser** 30 cm Tiefe Trend	p	r^2	**Bodensickerwasser** 60 cm Tiefe Trend	p	r^2	**Bodensickerwasser** 80 cm Tiefe Trend	p	r^2	**Bachwasser** Trend	p	r^2
H^+	($\mu mol_c\ l^{-1}$)			a			a			a			a
NH_4^+	($\mu mol_c\ l^{-1}$)			a			a			a			a
Na^+	($\mu mol_c\ l^{-1}$)	+5,5	***	0,40			a			a	-5,1	*	0,56
K^+	($\mu mol_c\ l^{-1}$)			a			a			a			a
Ca^{2+}	($\mu mol_c\ l^{-1}$)	-24,6	***	0,47	-11,6	***	0,72	-8,0	***	0,46	-24,7	***	0,38
Mg^{2+}	($\mu mol_c\ l^{-1}$)			a	-6,3	***	0,46			a	-4,9	*	0,12
NO_3^-	($\mu mol_c\ l^{-1}$)	-6,3	**	0,43	-3,9	*	0,27	-9,0	***	0,49	-17,4	***	0,73
SO_4^{2-}	($\mu mol_c\ l^{-1}$)	-59,6	***	0,30	-68,0	***	0,58	-55,1	**	0,28	-41,2	***	0,41
Cl^-	($\mu mol_c\ l^{-1}$)		ns	0,24			a			a	-9,2	**	0,77
Al_{ges}	($\mu g\ l^{-1}$)			a	-559	***	0,64	-667	***	0,34	-290	***	0,58
Mn_{gest}	($\mu g\ l^{-1}$)	-4,1	*	0,23			a		ns	0,42	-14,2	***	0,46
Fe_{ges}	($\mu g\ l^{-1}$)		ns	0,22			a			a		ns	0,19
DOC	($mg\ l^{-1}$)			a		ns	0,38	-0,9	***	0,52		ns	0,27
ANC	($\mu mol\ l^{-1}$)	+45,8	**	0,33	+57,0	***	0,52	+59,9	***	0,35	+44,5	***	0,61
ΣBC^b	($\mu mol_c\ l^{-1}$)	-26,1	**	0,31	-18,4	***	0,45		ns	0,19	-23,2	**	0,29
ΣA^c	($\mu mol_c\ l^{-1}$)	-67,6	**	0,38	-76,4	***	0,60	-62,5	**	0,34	-67,8	***	0,50

*** $p < 0{,}001$; ** $p < 0{,}01$; * $p < 0{,}05$; ns nicht signifikant
[a] Modell nicht signifikant
[b] Summe „basischer“ Kationen ($[Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}]$)
[c] Summe der Anionen starker Säuren ($[Cl^-] + [NO_3^-] + [SO_4^{2-}]$)

Wie schon für Schluchsee gezeigt, sind die Bestimmtheitsmaße des Zeitreihenmodells (r^2) im Bachwasser höher als im Bodensickerwasser.

Die Zeitreihen von NO_3^- im Bachwasser zeigen in den beiden Einzugsgebieten sehr unterschiedliche zeitliche Dynamiken (Abb. 5; Tab. 4 u. Tab. 5). In Schluchsee, wo eine Abnahme der N-Deposition festzustellen ist (Tab. 3), stieg die NO_3^--Konzentration im Bachwasser schwach an (Abb. 5a). Im Rotherdbach (Abb. 5b) ist dagegen ein starker Konzentrationsrückgang zu beobachten. Die N-Deposition ist in diesem Untersuchungsgebiet nur im Freilandniederschlag schwach rückläufig (Tab. 3). Zudem ist bei Rotherdbach die jahreszeitliche Saisonalität der NO_3^--Konzentration im Bachwasser deutlich geringer ausgeprägt als bei Schluchsee.

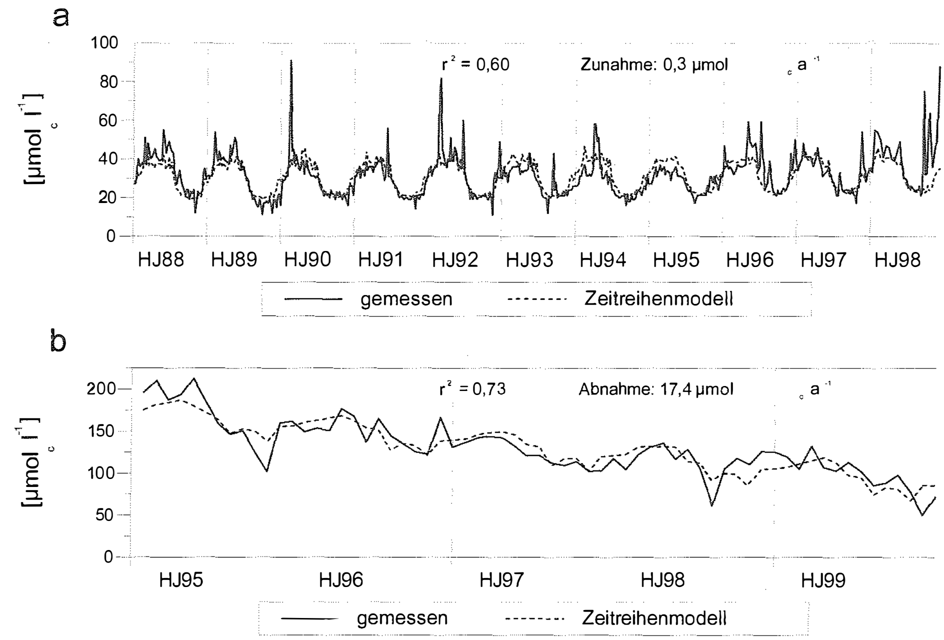


Abb. 5: Nitrat-Konzentrationen im Bachwasser der Einzugsgebiete ***Schluchsee*** (a) und ***Rotherdbach*** (b). Vergleich der Messwerte mit den Vorhersagen des Zeitreihenmodells.

Fig. 5: Nitrate concentrations in streamwater. Comparison between measured (gemessen) and predicted (Zeitreihenmodell: time series model) values in ***Schluchsee*** (a) and ***Rotherdbach*** catmchent (b).

Reaktion auf Kalkung

Einzugsgebiet Schluchsee

Nach Ausbringung des dolomitischen Kalkes sind ab Oktober 1990 Auswirkungen auf den Konzentrationsverlauf im Sickerwasser in ***Schluchsee*** zu erkennen. Deutliche Effekte sind hier v.a. beim pH-Wert, der Säureneutralisationskapazität (SNK) sowie der Ca^{2+}- und Mg^{2+}-Konzentration vorhanden (Abb. 6). Für Mg^{2+} ist im Gegensatz zu Ca^{2+} auch im tieferen Mineralboden ein über mehrere Jahre hin anhaltender Effekt der Kalkung zu sehen. Im Bachwasser ist dagegen nur für Mg^{2+} ein deutlicher Einfluss der Kalkung zu erkennen. Um die Auswirkungen der Kalkung differenziert zu betrachten, wurden die Konzentrationen im Bachwasser vor und nach der Kalkung dem parameterfreien MWU-Test unterzogen (Tab. 6). Es wird deutlich, dass bereits vor der Kalkung gewisse hydrochemische Unterschiede zwischen den beiden Gebieten bestanden.

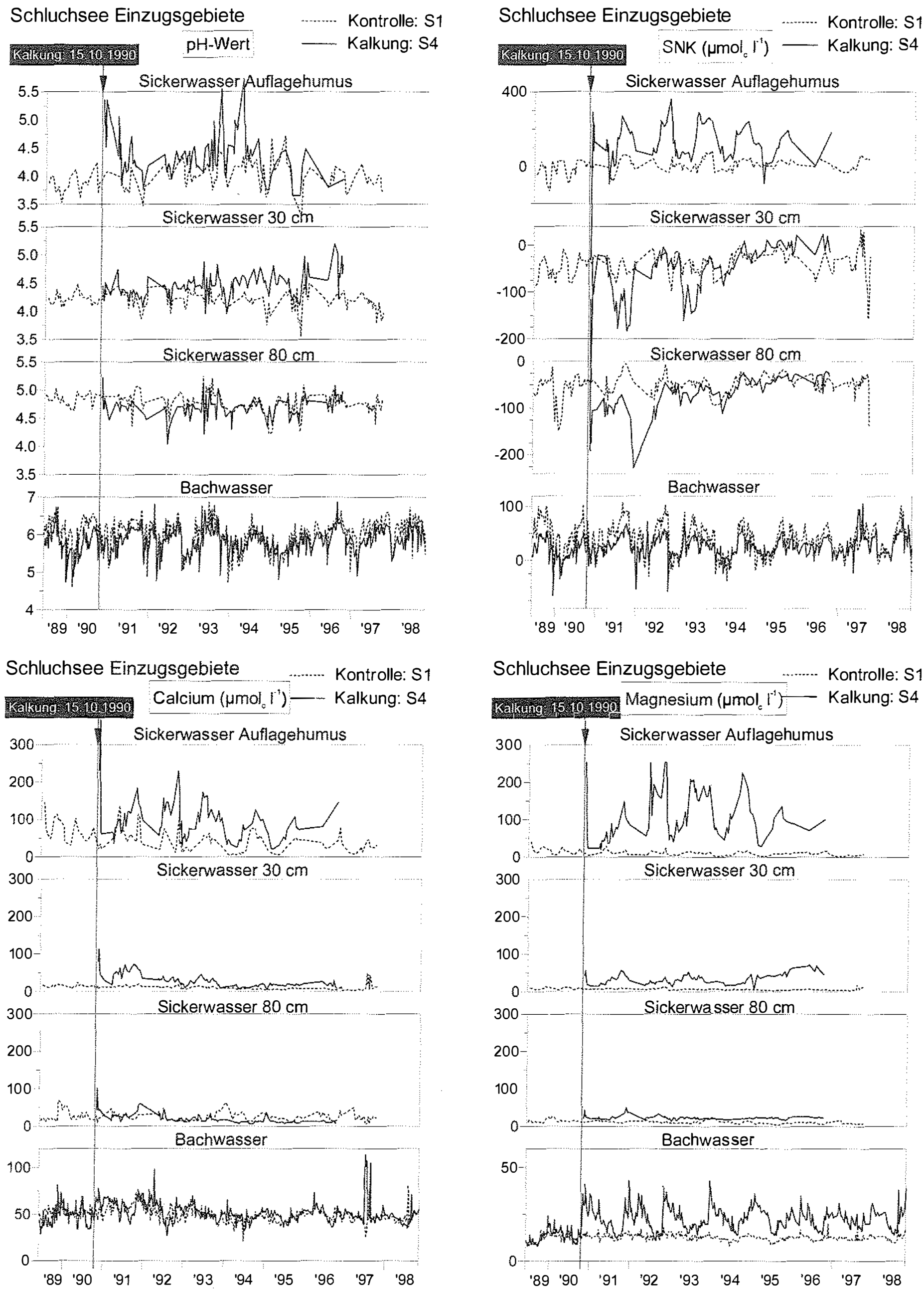


Abb. 6: pH-Wert, Säureneutralisationskapazität (SNK) sowie Konzentrationsverläufe von Ca^{2+} und Mg^{2+} im Sickerwasser und Bachwasser der Einzugsgebiete Schluchsee (S1: Kontrolle; S4: Kalkung).

Fig. 6: pH-Value, acid neutralizing capacity (SNK) and concentrations of Ca^{2+} and Mg^{2+} in soil water and streamwater of Schluchsee catchments (S1 : control; S4: limed).

Demnach lässt sich bei Betrachtung des gesamten Datenkollektivs ein signifikanter Kalkungseinfluss nur in Form höherer Ca^{2+}- und geringerer Al^{3+}-Konzentrationen absichern. Werden nur die „Hochwasserproben“ betrachtet, sind allerdings in S4 signifikant niedrigere Konzentrationen von Al^{3+}, Al_{ges} und Mn_{ges} zu erkennen. Signifikant höher liegen die SNK-Werte sowie die Ca^{2+}- Cl^{-}- und DOC-Konzentrationen. Magnesium zeigte auch vor Kalkausbringung in S4 bei Hochwasserabflüssen signifikant höhere Konzentrationen. Allerdings spricht der deutlich erhöhte Konzentrationsmittelwert nach der Kalkung für eine Zunahme der Mg^{2+}-Konzentrationen durch die Kalkung, was auch die graphische Darstellung der Konzentrationszeitreihen verdeutlicht (Abb. 6). Die forstübliche Dolomit-Ausbringung bewirkte somit bei höheren Abflüssen eine tendenziell leicht verbesserte Säurepufferung.

Tab. 6: Vergleich der Konzentrationen (arithmetische Mittelwerte bei wöchentlicher Probenahme) im Bachwasser von Kontrollgebiet S1 und gekalktem Gebiet S4 vor bzw. nach der Kalkung in ***Schluchsee***.

Table 6: Comparison of concentrations (average of weekly sampling) in the stream water of control watershed S1 and watershed S4 before and after liming in ***Schluchsee***.

Parameter	**Alle Werte**						**Hochwasserwerte** [a]					
	Vor Kalkung (1.11.89 - 1.10.90)			**Nach Kalkung** (1.11.90 - 31.10.98)			**Vor Kalkung** (1.11.89 - 1.10.90)			**Nach Kalkung** (1.11.90 - 31.10.98)		
	S1 *n = 58*		**S4** *n = 56*	**S1** *n = 376*		**S4** *n = 373*	**S1** *n = 14*		**S4** *n = 15*	**S1** *n = 72*		**S4** *n = 65*
pH-Wert	5,91	**	5,58	6,00	**	5,84	5,00		5,09	5,42		5,47
Na^{+} [$\mu mol_c\ l^{-1}$]	75,3	**	62,4	80,5	**	71,4	46,3		43,1	56,3		57,1
K^{+} "	14,3	**	12,2	14,5	**	12,3	14,2		13,6	13,8		13,3
Ca^{2+} "	54,4		51,9	49,7	*	52,1	52,4		56,5	47,0	**	56,9
Mg^{2+} "	13,5	**	15,4	12,7	**	22,8	14,6	**	18,1	13,5	**	30,4
Al^{3+} "	11,8	**	16,1	7,5		6,5	36,9		36,0	20,0	**	13,9
NO_3^{-} "	35,3	*	28,0	31,2	**	27,3	50,9		43,6	37,2		36,4
SO_4^{2-} "	74,9	**	86,9	69,7	**	78,8	79,8	**	88,1	73,7	**	81,1
Cl^{-} "	18,7	**	20,2	19,0	**	25,4	19,3		20,5	19,8	**	30,0
HCO_3^{-} "	40,6	**	20,6	50,1	**	33,5	11,5		12,5	21,4		21,5
SNK "	28,5	**	6,7	37,8	**	27,4	-22,3		-20,9	0,2	**	10,4
Al_{ges} [$\mu g\ L^{-1}$]	210,2	**	281,5	151,5	**	184,5	487,8		489,4	312,3		275,5
Mn_{ges} "	13,9	**	20,4	9,2	**	9,6	35,1		36,1	21,2	**	18,0
Fe_{ges} "	7,7	**	17,1	7,5	**	16,4	14,6	*	21,7	9,1	**	15,2
DOC [$mg\ L^{-1}$]	1,1	*	1,5	1,4	**	2,1	1,6		1,9	1,7	**	2,4

* $p < 0,05$; ** $p < 0,01$; MWU-Test (Mann-Whitney-U-Test)

[a] Probenahmen mit Abflußwerten höher als 80 % Perzentil (S1: $Q > 7,1\ L\ s^{-1}$; S4: $Q > 4,9\ L\ s^{-1}$)

Zur Betrachtung der zeitlichen Veränderungen nach Kalkung wurden die Konzentrationen von Ca^{2+}, Mg^{2+} und Al^{3+} sowie die SNK bei Hochwasserabflüssen getrennt nach hydrologischen Jahren (HJ) untersucht (Abb. 7). Während für Ca^{2+} und Al^{3+} bei Betrachtung der Einzeljahre 4 Jahre nach Ausbringung keine signifikanten Unterschiede zwischen den Gebieten nachzuweisen sind, ist die Mg^{2+}-Konzentration in S4 auch 7 Jahre nach Kalkung deutlich gegenüber dem Wert davor erhöht. Im Jahr 1998 sind die Unterschiede dann aber statistisch nicht mehr absicherbar. Auch für die SNK sind 6 Jahre nach Ausbringung keine signifikanten Unterschiede vorhanden. Ähnliche Tendenzen zeigen auch die vergleichenden Analysen hochauflösend beprobter Hochwasserereignisse nach Kalkausbringung (2, 3, 6 bzw. 7 Jahre nach Ausbringung; nicht dargestellt).

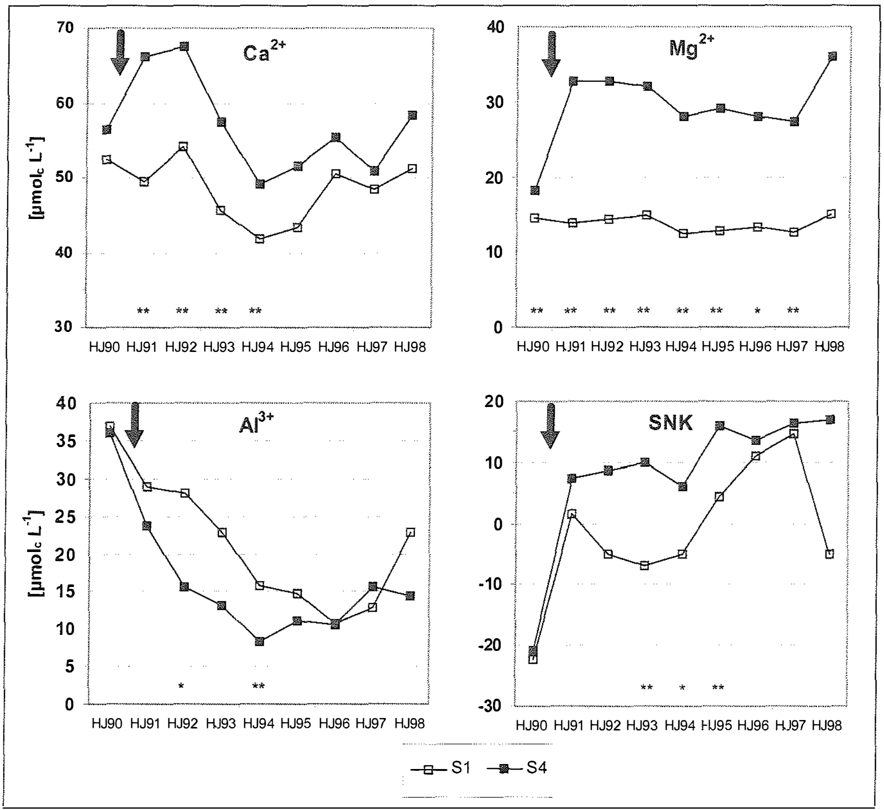


Abb. 7: Vergleich der zeitlichen Entwicklung der Konzentrationen von Ca^{2+}, Mg^{2+}, Al^{3+} sowie der SNK im Hochwasserabfluss (vgl. Tab. 3.5; * p < 0,05, ** p < 0,01) der Einzugsgebiete S1 und S4 in ***Schluchsee***. Der Pfeil markiert den Zeitpunkt der Kalkung von Einzugsgebiet S4; HJ = hydrologisches Jahr.

Fig. 7: Comparison of the temporal evolution of concentrations of Ca^{2+}, Mg^{2+}, Al^{3+} and the acid neutralizing capacity (SNK) at high discharge in watersheds Sl and S4 (***Schluchsee*** site). (cf. Table 3.5; * p < 0.05, ** p < 0.01). The arrow marks the date of dolomite application to watershed S4; HJ = hydrological year.

Einzugsgebiet Rotherdbach

Am Standort ***Rotherdbach*** gibt es kein vergleichbares unbehandeltes Einzugsgebiet, so dass für die Analyse der Kalkungseinflüsse auf die Gewässerchemie nur der zeitliche Konzentrationsverlauf nach Kalkung zur Verfügung steht. Allerdings sind innerhalb des Einzugsgebietes Bodensickerwasser-Messstellen sowohl im gekalkten als auch in einem gezielt von der Kalkung ausgenommenen Bereich vorhanden. Der Vergleich der Konzentrationsverläufe dieser beiden Bereiche zeigt in der beobachten Bodentiefe von ca. 80 cm allerdings keine Einflüsse der Behandlung (nicht dargestellt). Unmittelbar nach der Kalkung war dagegen im Bachwasser des Rotherdbaches ein deutlicher Einfluss der Kalkung erkennbar (Abb. 8). Dabei handelt es sich um eine kurzfristige starke Beeinflussung durch direkt in das Gewässer und die vernässten Gewässerrandbereiche gelangtem Kalk.

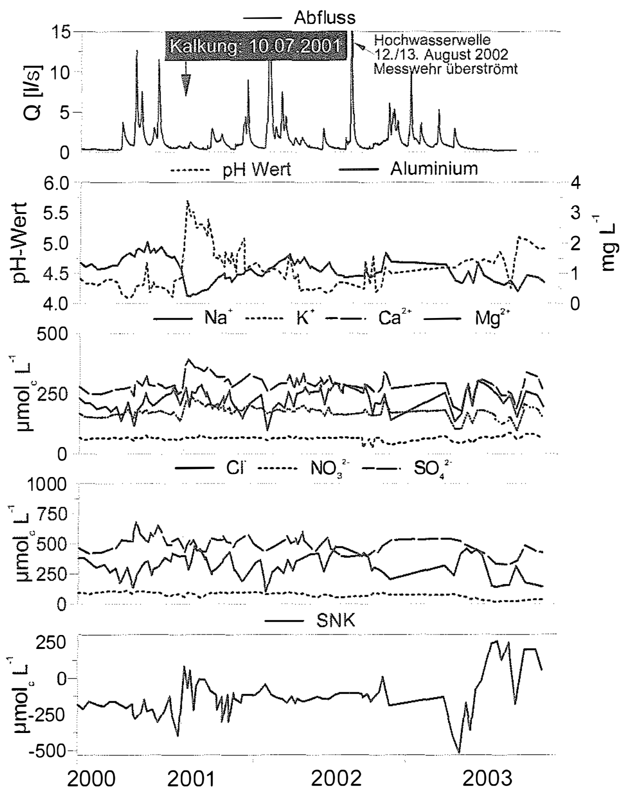


Abb. 8: Initialeffekte einer Dolomitkalkung auf den Bachwasser-Chemismus im Einzugsgebiet ***Rotherdbach.***

Fig. 8: Initial effects of dolomite limestone application on streamwater chemistry in the ***Rotherdbach*** catchment.

Die durch die Kalkung schlagartig erhöhten pH-Werte und die erniedrigten Al-Konzentrationen haben sich daher relativ schnell wieder an ihre Ausgangswerte angeglichen. Gleiches gilt für die ebenfalls kurzfristig erhöhten Ca^{2+}- und Mg^{2+}-Konzentrationen im Vorfluter. 2½ Jahre nach der Kalkung sind daher außer den oben genannten kurzfristigen Einflüssen durch direkten Kalkeintrag in das Gewässer bislang keine weiteren, langfristigen Effekte der Kalkung auf den Gewässerchemismus zu erkennen. Die visuell erkennbare Zunahme der Säureneutralisationskapazität (SNK) ist in Zusammenhang mit der seit Beginn der Untersuchungen festgestellten Zunahme der SNK zu interpretieren (vgl. 3.2.2). Durch die Eintragsrückgänge (siehe oben) kommt es am Standort ***Rotherdbach*** langfristig im Vorfluter ebenfalls zu einer Abnahme der Protonen-, Sulfat- und auch der Aluminiumkonzentrationen die in der Summe zu einer Zunahme der Säureneutralisationskapazität im Bachwasser führen.

DISKUSSION

Einflüsse veränderter atmosphärischer Deposition

Die beiden Untersuchungsgebiete weisen ein deutlich unterschiedliches Depositionsklima auf. Während Schluchsee vergleichsweise gering atmogen belastet ist, war das Einzugsgebiet Rotherdbach bis in die jüngste Vergangenheit hinein durch extrem hohe Stoffeinträge (v.a. von S) geprägt. Trotz der unterschiedlichen S-Eintragsniveaus sind an beiden Standorten im letzten Jahrzehnt signifikante Rückgänge der S-Einträge erkennbar. Die Stoffbilanz zwischen Eintrag und Austrag zeigt in beiden Gebieten eine Netto-S-Freisetzung. Offensichtlich wird in beiden Gebieten der zu Zeiten hoher S-Einträge im Boden gespeicherte Schwefel bei den rückläufigen Einträgen remobilisiert. Neben dieser Freisetzung anorganisch gebundenen Schwefels ist am Standort Schluchsee allerdings der sehr hohe Anteil organisch gebundenen Schwefels (78 % der S-Menge im Boden; Prietzel, 1998), der auch Fluktuationen unterworfen sein kann, zu beachten. Im Rotherdbach-Gebiet stellt dagegen die anorganische Fraktion den Hauptanteil des gespeicherten S im Boden dar (Prietzel persönl. Mitteilung). Im Bodensickerwasser und im Bachwasser führt der Rückgang der S-Deposition zu einem Rückgang der SO_4^{2-}-Konzentrationen. Dabei sind in beiden Gebieten die Rückgänge im Sickerwasser stärker als im Bachwasser. Offensichtlich ist auch in der tieferen Sickerstrecke zwischen der Messebene des tiefen Sickerwassers (80 cm) und dem Vorfluter noch reversibel freisetzbarer Schwefel gespeichert. Auf die Bedeutung in der Zersatzzone gespeicherten Schwefels für den Austrag hatten auch Manderscheid et al. (2000) hingewiesen.

Die Rückgänge beim Hauptanion SO_4^{2-} führten im Bodensickerwasser und Bachwasser auch zu Rückgängen in der Summe der „basischen" Kationen ($Na^+ + K^+ + Ca^{2+} + Mg^{2+}$) sowie bei Al_{ges}. Bei einem gleichzeitigen Rückgang der Einträge „basischer" Kationen (v.a. Ca^{2+}, Mg^{2+}), der an den Untersuchungsgebieten festgestellt wurde, sind negative Einflüsse eines S-Depositionsrückgangs auf die Pufferkapazität nicht auszuschließen (Meesenburg et al., 1995) In beiden Untersuchungsgebieten war allerdings der Rückgang „basischer" Kationen im Sickerwasser (Ausnahme: Rotherdbach 80 cm: kein signifikanter Trend) deutlich geringer als der Rückgang bei SO_4^{2-} und der Anionensumme. Dadurch stieg die Säureneutralisationskapazität (SNK) in allen betrachteten Sickerwassertiefen signifikant an. Ein SNK-Rückgang im Sickerwasser als Folge abnehmender Ca-(Mg-)Einträge konnte nicht festgestellt werden. Im Gegensatz zu der an beiden Standorten im Sickerwasser festgestellten SNK-Zunahme lässt sich für Schluchsee im Bachwasser keine Veränderung bei dieser zentralen Versauerungskenngröße nachweisen. In Bachwasser des Rotherdbach-Einzugsgebietes ist dagegen eine starke SNK-Zunahme ausgeprägt, die als Reversibilität der Gewässerversauerung interpretiert werden kann. Allerdings ist die SNK an diesem Standort im Mittel noch negativ, während sie am Standort Schluchsee neutral bis schwach positiv ist (Armbruster, 1998). Insgesamt fügt sich die in Schluchsee beobachtete Entwicklung gut in das Bild zweier flächendeckender hydrochemischer Inventuren an Oberflächengewässern im gesamten Schwarzwald ein, die im Abstand von 10 Jahren erfolgten (Zöttl et al., 1985; Feger et al., 1995).

Die Konzentrationstrends von NO_3^- im Bachwasser sind gerade im Hinblick auf mögliche Veränderungen der N-Retentionskapazität interessant. Hier erstaunt zunächst, dass trotz leichtem Rückgang der N-Deposition im Bachwasser des Schluchsee-Gebiets ein gegenläufiger Trend, also eine Zunahme der NO_3^--Konzentrationen, zu beobachten ist. Armbruster (1998) ermittelte bei der Analyse einer etwas kürzeren Zeitreihe (1988-1995) in Schluchsee bei nahezu unveränderten N-Einträgen einen leichten Rückgang der NO_3^--Konzentrationen im Bachwasser. Bei Betrachtung des Zeitverlaufs (Abb. 3.4) fällt auf, dass v.a. in den letzten beiden Untersuchungsjahren erhöhte NO_3^--Konzentrationen und eine stärker ausgeprägte Saisonalität beobachtet wurden. Hier machen sich offenbar Auswirkungen eines starken Schneebruchs im Winter 1996/97 bemerkbar. In den entstandenen Lücken kam es offenbar wegen des dort erhöhten Wärme- und Lichtangebotes zu einer intensiveren Mineralisation (Fink et al., 1999). Im Bachwasser des Rotherdbach-Einzugsgebietes wurde dagegen ein ausgeprägter Rückgang der NO_3^--Konzentrationen ermittelt, obwohl die N-Deposition nur andeutungsweise rückläufig ist. Denkbar ist hier ein Einfluss der stark zurück gegangenen S- und Säuredeposition im Gebiet, der zu einer erhöhten Vitalität von Bestand und Bodenmikroorganismen und dadurch einer verstärkten N-Retention im terrestrischen Ökosystem geführt haben könnte. Ein Rückgang von NO_3^- im Bachwasser wurde für Gebiete des Tschechischen Republik auch von Veselý et al. (2002) beschrieben. Bis heute fehlt allerdings eine eindeutige Erklärung für diese Trends, die der Hypothese einer abnehmenden Retentionskapazität für Stickstoff widersprechen.

Reaktion auf praxisübliche Kalkung

Die einmalige Ausbringung von 4 t ha^{-1} dolomitischem Kalk in ***Schluchsee*** hatte insgesamt nur geringe Auswirkungen auf die chemische Zusammensetzung des Gebietsabflusses. Die Lösung des oberflächlich ausgebrachten Dolomitkalkes schreitet nur sehr langsam voran. Wie wiederholte Bodeninventuren zeigten, hatte die Kalkung nur eine geringe bodenchemische Tiefenwirkung (d.h. höhere Basensättigung und höhere pH-Werte) zur Folge (vgl. Raspe und Feger, 1998). Somit waren die Austauschgleichgewichte im Mineralboden kaum verändert, so dass auch die chemische Zusammensetzung des tieferen Sickerwassers kaum variierte (vgl. Armbruster und Feger, 1998).

Bei erhöhten Abflüssen war nach Kalkung eine leicht verbesserte Säurepufferung zu beobachten. Nyström et al. (1995) bewerten leichte Erhöhungen in der SNK, besonders wenn sie in Perioden episodischer Versauerung auftreten, als positive Effekte von Einzugsgebietskalkungen, weil dadurch in stark versauerten Einzugsgebieten toxische Parameter für Biota (v.a. Al^{3+}) unterschritten werden können. Vermutlich hat die Kalkung von Einzugsgebiet S4 auch zu einer Verminderung der episodischen Versauerung in Zeiträumen geführt, die für aquatische Organismen als besonders kritisch zu betrachten sind (z.B. Frühjahrshochwasser nach Schneeschmelze). Allerdings ist fraglich, inwieweit die Verhältnisse der untersuchten Herbsthochwässer auf die Schneeschmelze zu übertragen sind. In der zeitlichen Entwicklung zeigte sich bei Betrachtung der Hochwasserabflüsse der Routinebeprobung in ***Schluchsee*** eine tendenzielle Abnahme der verbesserten Säurepufferung. Detaillierte Untersuchungen von einzelnen Hochwasserereignissen lassen allerdings auch 7 Jahre nach Kalkausbringung noch eine verbesserte Säurepufferung im Abfluss des gekalkten Wassereinzugsgebiets erkennen (Armbruster et al., 2000).

Im Sickerwasser unterhalb des Hauptwurzelraumes zeigen sich dagegen im Einzugsgebiet ***Rotherdbach*** auch 2½ Jahre nach Kalkausbringung keine Einflüsse der Kalkausbringung auf die chemische Zusammensetzung. Die kurzfristig nach der Kalkung durch direkt in das Gewässer gelangten Kalk erhöhten pH-Werte entsprechen wieder den Ausgangsbedingungen vor der Kalkung. Längerfristige Effekte der Kalkung auf den Gewässerchemismus waren bislang nicht zu erkennen.

An beiden Standorten war allerdings das Nitrifikationspotential nach Kalkung deutlich erhöht (Armbruster und Feger, 2002; Armbruster et al., 2004). Bei der Planung großflächiger Kalkungen ist deshalb nicht nur der Bodenversauerungszustand, sondern auch das Umsetzungspotential der organischen Substanz und die damit verbundenen Risiken für die Sickerwasserqualität zu berücksichtigen. An vielen Standorten hat sich trotz zunehmender Bodenversauerung depositions- bzw. bewirtschaftungsbedingt gleichzeitig auch die N-Verfügbarkeit verbessert. Um gewässerschutzrelevante Bodenfunktionen nachhaltig zu sichern, müssen solche Bodenveränderungen unbedingt mit berücksichtigt werden. Für die Praxis der Bodenschutzkalkung bedeutet dies, dass den differenzierten Verhältnissen am jeweiligen Standort hinreichend Rechnung zu tragen ist (Feger, 1997/98; Leube, 2000).

DANKSAGUNG

Die Arbeiten wurden aus Mitteln des Landes Baden-Württemberg (PEF, Forschungszentrum Karlsruhe), des Bundesministeriums für Bildung und Forschung (BMBF) und des Landes Sachsen (Sächsisches Staatsministerium für Umwelt und Landwirtschaft) gefördert.

LITERATUR

Abiy M., 1998: Standortskundliche und hydrochemische Untersuchungen in zwei Wassereinzugsgebieten des Osterzgebirges. Dissertation TU Dresden.

Alewell C., 1995: Sulfat-Dynamik in sauren Waldböden – Sorptionsvermögen und Prognose bei nachlassenden Depositionen. Bayreuther Forum Ökologie **19**. 185 S.

Alewell C., Armbruster M., Bittersohl J., Evans C., Meesenburg H., Moritz K. und A. Prechtel; 2001: Are there signs of acidification reversal after two decades of reduced acid input in the low mountain ranges of Germany? Hydrol. and Earth Syst. Sci. **5**: 367-378.

Alewell C., Manderscheid B., Gerstberger P. und E. Matzner; 2000: Effects of reduced atmospheric deposition on soil solution chemistry and elemental contents of spruce needles in NE-Bavaria, Germany. J. Plant Nutr. Soil. Sci **163**: 509-516.

Armbruster M., 1998: Zeitliche Dynamik der Wasser- und Elementflüsse in Waldökosystemen. Freiburger Bodenkundl. Abh. **38**. 301 S.

Armbruster M. und K.H. Feger; 1998: Zusammensetzung der Bodenlösung und Veränderung durch Düngung. - In: Raspe S., Feger K.H. und H.W. Zöttl; (Hrsg.): Ökosystemforschung im Schwarzwald - Auswirkungen von atmogenen Einträgen und Restabilisierungsmaßnahmen in Fichtenwäldern (Verbundprojekt ARINUS). Umweltforschung in Baden-Württemberg, Ecomed-Verlag, Landsberg. 179-203.

Armbruster M. und K.H. Feger; 2002: Verbessert Waldbodenkalkung den Zustand unserer Gewässer? Mitteilungen der Deutschen Bodenkundlichen Gesellschaft **98**: 27-28.

Armbruster M., Köhler H. und K-H. Feger; 2000: Chemische Zusammensetzung zweier quellnaher Waldbäche im Hochschwarzwald - Abflussabhängige Variabilität und Einfluss einer Bodenschutzkalkung. Forstw. Cbl. **119**: 249-262.

Armbruster M., Schulz N., Seegert J. und K.H. Feger; 2004: Stoffflüsse nach Waldumbau (Buchen-Voranbau und Kalkung) auf der Basis des Wassereinzugsgebietes Rotherdbach in den mittleren Berglagen. – Endbericht; F+E-Vorhaben gefördert durch das Sächsische Staatsministerium für Umwelt und Landwirtschaft. 60 S.

Brahmer G., 1990: Wasser- und Stoffbilanzen bewaldeter Einzugsgebiete im Schwarzwald unter besonderer Berücksichtigung naturräumlicher Ausstattung und atmogener Einträge. Freiburger Bodenkundl. Abh. 25. 295 S.

Feger K.H., 1993: Bedeutung von ökosysteminternen Umsätzen und Nutzungseingriffen für den Stoffhaushalt von Waldökosystemen. Freiburger Bodenkundl. Abh. 31. 237 S.

Feger K.H., 1996: Schutz vor Säuren. In: Blume H.P., Fischer W., Frede H.G., Horn R., Felix-Henningsen P., Stahr K.; (Hrsg.): Handbuch der Bodenkunde, ecomed-Verlag Landsberg. Kap. 7.6.2. 24 S.

Feger K.H., 1997/98: Boden- und Wasserschutz in mitteleuropäischen Wäldern - I. Rahmenbedingungen. - Bodenschutz 2: 18-23; II. Gefährdungspotentiale und Bewertung. - Bodenschutz **2**: 134-138; III. Waldbauliche Möglichkeiten und Maßnahmen des technischen Bodenschutzes. - Bodenschutz **3**: 103-108.

Feger K.H., Martin D. und H.W. Zöttl; 1995: Entwicklung der Gewässerazidität im Schwarzwald - sind depositionsbedingte Veränderungen erkennbar? - Die Naturwissenschaften **82**: 420-423.

Fink S., Feger K.H., Gülpen M., Armbruster M. und K. Lorenz; 1999: Magnesium-Mangelvergilbung an Fichte - Einfluß von frühsommerlicher Trockenheit und Dolomit-Kalkung. FZKA-BWPLUS-Berichtsreihe **25**: http://bwplus.fzk.de/berichte/SBer/PEF197001SBer.pdf.

Flieger A. und H. Toutenburg; 1995: SPSS Trends für Windows. Arbeitsbuch für Praktiker. Prentice Hall Verlag, München. 147 S.

Langusch J., 1995: Untersuchungen zum Ionenhaushalt zweier Wassereinzugsgebiete in verschiedenen Höhenlagen des Osterzgebirges. Dissertation TU Dresden.

Leube F., 2000: Leitfaden Forstliche Bodenschutzkalkung in Sachsen. Sächsische Landesanstalt für Forsten (Hrsg.); Schriftenreihe der Sächsischen Landesanstalt für Forsten 21. 58 S.

Likens G.E., Bormann F.H., Pierce R.S., Eaton J.S. und N.M. Johnson; 1977: Biogeochemistry of a forested catchment. Springer Verlag, New York.

Manderscheid B., Schweisser T., Lischeid G., Alewell C. und E. Matzner; 2000: Sulfate pools in the weathered bedrock of a forested catchment. Soil Sci. Soc. Am. J. **64**: 1078–1082.

Meesenburg H., Meiwes K.J. und P. Rademacher; 1995: Long term trends in atmospheric deposition and seepage in northwest German forest ecosystems. Water, Air and Soil Pollution **85**: 611-616.

Moldan F. und R.F. Wright; 1998: Changes in runoff chemistry after five years of N addition to a forested catchment at Gardsjön, Sweden. Forest Ecol. and Management **101**: 187-197.

Nebe W., Abiy M., Hofmann W. und Weiske A.; 1998: Standorte der Experimentalflächen. In: Nebe W., Roloff A. und M. Vogel (Hrsg.); Untersuchungen von Waldökosystemen im Erzgebirge als Grundlage für einen ökologisch begründeten Waldumbau. - Forstwiss. Beiträge Tharandt 4: 19-27.

Nyström U., Hultberg H. und B.B. Lind; 1995: Can forest-soil liming migrate acidification of surface waters in Sweden. - Water, Air and Soil Pollution **85**: 1855-1860.

Prietzel J., 1998: Untersuchungen zum S-Haushalt – Zusammenfassende Diskussion. In: Raspe S., Feger K.H. und H.W. Zöttl (Hrsg.); Ökoystemforschung im Schwarzwald. Auswirkungen von atmogenen Einträgen und Restabilisierungsmaßnahmen auf den Wasser- und Stoffhaushalt von Fichtenwäldern. Verbundprojekt ARINUS. Umweltforschung in Baden-Württemberg, ecomed Verlag, Landsberg. 375-386.

Raspe S. und K.H. Feger; 1998: Bodenfestphase und behandlungsbedingte Veränderungen. - In: Raspe S., Feger K.H. und H.W. Zöttl; (Hrsg.): Ökosystemforschung im Schwarzwald - Auswirkungen von atmogenen Einträgen und Restabilisierungsmaßnahmen in Fichtenwäldern (Verbundprojekt ARINUS). Umweltforschung in Baden-Württemberg, ecomed-Verlag, Landsberg. 203-222.

Raspe S., Feger K.H. und H.W. Zöttl (Hrsg.); 1998: Ökoystemforschung im Schwarzwald. Auswirkungen von atmogenen Einträgen und Restabilisierungsmaßnahmen auf den Wasser- und Stoffhaushalt von Fichtenwäldern. Verbundprojekt ARINUS. Umweltforschung in Baden-Württemberg, ecomed Verlag. Landsberg. 533 S.

Reuss J.O. und D.W. Johnson; 1986: Acid deposition and the acidification of soils and waters. Ecological Studies 59, Springer Verlag. New York.

Stoddard J.L., Jeffries D.S., Lükewille A., Clair T.A., Dillon P.J., Driscoll C.T., Forsius M., Johannessen M., Kahl J.S., Kellog J.H., Kemp A., Mannio J., Monteith D.T., Murdoch P.S., Patrick S., Rebsdorf A., Skjelkvale B.L., Stainton M.P., Traaen T., van Dam H., Webster K.E., Wieting J. und A. Wilander; 1999: Regional trends in aquatic recovery from acidification in North America and Europe. Nature **401**: 575-578.

Tarrasón,L. und J. Schaug (eds.); 1999: Transboundary acid deposition in Europe. EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe) summary report 1999. Norwegian Meteorological Institute Research Report 83.

Ulrich B., 1983: Interactions of forest canopies with atmospheric constituents: SO_2 alkali and earth alkali cations and chroride. In: Ulrich B. und J. Pankrats (Hrsg.); Effects of air pollutants in forest ecosystems. Reidel Publ. Co., Dordrecht. 33-45.

Ulrich,B., 1991: Rechenweg zur Schätzung der Flüsse in Waldökosystemen. Identifizierung der sie bedingenden Prozesse. In: Volker G. und J. Friedrich (eds.); Beiträge zur Methodik der Waldökosystemforschung. Ber. d. For. Zentr. Waldökosysteme (B) **24**: 204-210.

van Miegroet H., 1994: The relative importance of sulfur and nitrogen compounds in the acidification of fresh water. In: Steinberg C.E.W. and R.F. Wright (eds.); Acidification of freshwater ecosystems: Implications for the future. Dahlem workshop reports. Environmental sciences research report 14. Verlag Wiley & Sons, Chichester. 33-49.

Veselý J., Majer V., Norton S.A.; 2002: Heterogenous response of central European streams to decreased acidic atmospheric deposition. Environmental Pollution **120**: 275-281.

Zöttl H.W., Feger K.H. und G. Brahmer; 1985: Chemismus von Schwarzwaldgewässern während der Schneeschmelze 1984. - Die Naturwissenschaften **72**: 268-270.

Zöttl H.W., Stahr K. und K. Keilen; 1977: Bodenentwicklung und Standortseigenschaften im Gebiet des Bärhaldegranites (südlicher Hochschwarzwald). - Allg. Forst- u. Jagdz. **148**: 185-196.

WATER BALANCE OF A MIXED FOREST IN CENTRAL GERMANY – SMALL-SCALE VARIABILITY IN DEPENDENCE ON PATTERN OF LOCAL CANOPY COVER

WASSERHAUSHALT IN EINEM BUCHEN/FICHTEN-MISCHBESTAND NORDWESTDEUTSCHLANDS – KLEINRÄUMIGE VARIABILITÄT IN ABHÄNGIGKEIT DER LOKALEN ÜBERSCHIRMUNG

Michael BREDEMEIER*, Levis CHEUSSOM+, and Friedrich O. BEESE+

*Forest Ecosystems Research Centre and +Institute for Soil Science and Forest Nutrition, University of Göttingen, Büsgenweg 2, D-37077 Göttingen, Germany

ABSTRACT

The future approach of silviculture in Germany is clearly directed towards promotion of more natural forest types, at least for the publicly owned forest land. Pure conifer plantation stands which are still prevailing at present will gradually be replaced by mixed forests composed of native species. Among the expectations connected with this restructuring of the forest is a better risk control due to improved stability, e.g. against windthrow and pests, an enhanced flexibility of the wood assortments produced, and in the long run also an improvement of site quality. Consequently, the proportion of mixed forest in Germany and other central European countries will increase strongly. However, relatively little is known yet about how the new forest structures will affect important ecosystem processes. We investigate how the structure of a mixed forest of European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) generates small-scale heterogeneities in the water budget parameters. The measurements were carried out in tree groups within the mixed forest, where a central tree of one species was surrounded by neighbours from the other species. On the connecting lines from central tree to neighbouring trees, measurement transects were established. The local infiltration rates on the tree-to-tree transects may differ greatly depending on the local cover situation, i.e. the local forest canopy structure above the sampling point. Local mixed canopy cover generates local infiltration much closer to spruce cover than to beech cover. Based on these investigations, it seems possible to assess stand level water budgets by combining the small-scale patterns into a patchwork surface model.

ZUSAMMENFASSUNG

Die neuen Waldbaukonzepte in Deutschland und anderen mitteleuropäischen Ländern sehen eine starke Erhöhung des Mischwaldanteils an der Waldfläche vor, zumindest im öffentlichen Waldbesitz. Nadelholzreinbestände, die derzeit vielfach noch vorherrschen werden durch Mischbestände aus heimischen Arten ersetzt, die der natürlichen Waldgesellschaft nahe kommen sollen. Man erhofft sich durch diesen Waldumbau eine bessere Risikokontrolle bei erhöhter Stabilität der Bestände, zum Beispiele gegen Windwurf und Kalamitäten, Flexibilität bei den erzeugten Holzsortimenten, und langfristig auch eine Verbesserung der Standortqualität. Aufgrund dieser Waldbaupolitik

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 140-153
ÖGWEB (Österr Ges f Waldökoforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

steigt der Mischwaldanteil an, obwohl noch relativ wenig darüber bekannt ist, wie die neuen Waldstrukturen wichtige Prozesse im Ökosystem beeinflussen werden. Um hier zum Kenntnisstand beizutragen, untersuchten wir, wie die Kronenraumstruktur in einem Buchen- (*Fagus sylvatica*) Fichten-(*Picea abies*) Mischbestand kleinräumige Muster und Heterogenitäten in den Wasserhaushaltsparametern generiert. Die Messungen fanden in gemischten Baumgruppen statt, wo jeweils ein Zentralbaum der einen Art von Nachbarbäumen der anderen Art umgeben war. Auf den Verbindungslinien der Bäume wurden Messtransekte mit hoch auflösender Messung der Wasserhaushaltsparameter angelegt. Die lokalen Infiltrationsraten auf den Transekten zeigen deutliche Abhängigkeit von der lokalen Überschirmungssituation, wobei diese Abhängigkeit auch zeitlich variiert (Kontrast Sommer/Winter). Die Infiltrationsraten unter gemischter Überschirmung sind sehr viel näher an denen der reinen Fichtenüberschirmung als an denen unter reiner Buchenüberschirmung. Die Untersuchungen schaffen eine Grundlage, um flächenbezogene Wasserhaushaltsmodelle für Mischbestände auf der Basis des Mischungsmusters zu formulieren.

KEYWORDS: mixed forest, fagus silvatica, picea abies, hydrology, canopy structure, local cover, interception, throughfall, spatial pattern, water budget

INTRODUCTION

Background

Mixed forests composed of native tree species and close to the potential natural vegetation are today a prominent silvicultural goal in the management of forest ecosystems in Germany and other countries of central Europe (NMELF, 1996). This applies at least to the publicly owned forest land, where purely economic considerations rate lower than in private commercial forest enterprises.

Consequently, reconstruction (conversion) of monospecific forests into mixed forest stands has started and is still gaining momentum currently. In the mid- and higher altitudes, where Norway spruce (*picea abies* [L.] Karst.) monoculture plantation forest is still prevailing, conversion into mixed forest with the naturally dominating European beech (*Fagus silvatica* L.) is the most relevant silvicultural option (NMELF, 1996; Heitz, 2000). In practice, this is often done by planting beech seedlings under a thinned canopy of mature spruce, where natural regeneration of spruce is already present, and then subsequently removing the remaining mature stand (German "Buchen-Voranbau").

The benefits envisaged from the conversion of spruce monoculture forests to mixed beech/spruce forests comprise enhanced stability of the stands (better resistance to windthrow and drought stress due to improved rooting patterns) and upgraded site quality in the long run (predominantly owing to an improvement of the humus form). It is further expected that biodiversity in general would be enhanced in mixed forest stands compared to single species forest.

As a general consequence of this new silvicultural paradigm, the proportion of mixed forest in the total forest area of Germany and other European countries with similar forest policies will strongly increase.

However, while the forest conversion is proceeding in practice, science is still behind, and relatively little is known on how the new forest structures will influence central ecosystem processes such as water and nutrient fluxes, transfers and budgets. Our study is one of a small number of contributions to the investigation of the water relations in mixed forest stands versus pure stands. The starting question is: how will mixed forest composed of European beech and Norway spruce influence the water budget on different scales?

Hypotheses

To tackle this question, we put up a set of hypotheses for testing, with the central hypothesis: The water balance in mixed forest stands is different from the average value between the respective pure (mono-specific) stands.

Specific hypotheses comprise:

- Due to a different crown geometry in the mixture specific spatial canopy structures emerge.
- Spatio-temporal gap dynamics owing to the temporal defoliation of beech in mixed beech/spruce stands can be observed.
- These dynamics result in distinctly different patterns of local infiltration in mixed vs. pure forest stands.
- Spruce can profit from neighbouring beech trees due to enhanced water availability.

Objectives of the work presented here were to thoroughly test this set of hypotheses and to quantify the hypothesized relationships wherever feasible.

SITE AND MEASUREMENTS

The site of our study is located in the Solling, is a mountain range in the south of Lower Saxony in Germany. Solling ranges in elevation from 250 to 500 m a.s.l. and consists of a sandstone massive from the triassic geological formation of new red sandstone, located between the basins of the river Weser to the west and the river Leine to the east. It is a rural area of low population density with a high percentage of forest cover (60%). In the Solling area Dystric Cambisols and Cambic Podzols dominate (FAO classification). Texture of soil is usually silty loam.

Pure Norway spruce (*Picea abies* (L). Karst.) stands constitute 31% of the forests, pure European beech (*Fagus sylvatica* L.) 17% and mixed beech – coniferous stands 24% (NMELF, 1996).

The climate is sub-oceanic (Gravenhorst and Szarejko, 1990), with a mean annual precipitation of 1050 mm, mean annual temperature of 7°C (13.5°C during the vegetation season). Snow is present for about 145 days every year.

The mixed beech/spruce stand

The studied forest site is located at 51°43’ N, 9°38’ E at 400 m a.s.l. It is a European beech/Norway spruce mixed stand of about 120 years of age. The soil is a spodic, dystric cambisol from loess solifluction overlying smII sandstone. The site is designated as compartment 1083 in the state forest district of Uslar.

Within this site we chose two experimental plots, each of about 300 m^2 surface, defined as follows: the first one (Fig. 1) consists of a beech as central tree, surrounded by eight spruce trees (spruce dominated plot) and the second one has a spruce as central tree, surrounded by eight beech trees (beech dominated plot). The connecting straight lines between central tree and surrounding trees in each group were equipped as transects for our measurements of forest hydrological parameters.

The results on transect measurements shown further below refer to the example transect spruce F4 – beech central tree – spruce F8 in figure 1.

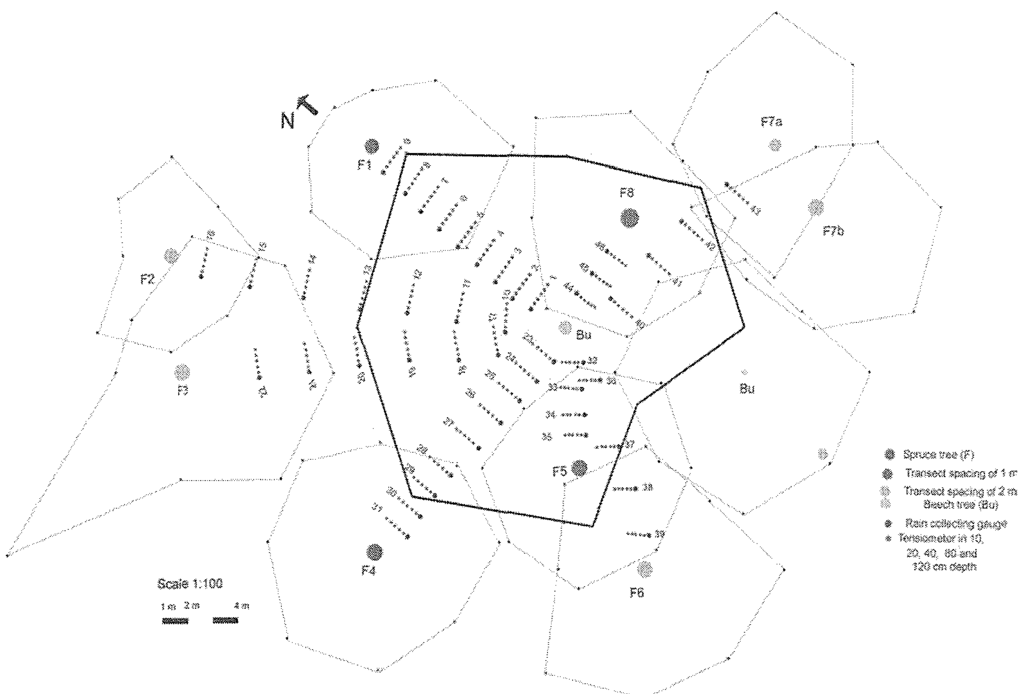


Fig.1 : Plot with beech as central tree (spruce dominated plot) – Abb. 1 : Plot mit Buche als Zentralbaum.

Installations and measurements

For the determination of the local amount of precipitation at each of the transect points, 99 rain collecting gauges were installed, 46 in the spruce dominated plot, 45 in the beech dominated plot and 8 in the open land. During the winter time, buckets replaced the rain collecting gauges. Additionally, the precipitation in the open land was recorded continuously to determine the daily open land precipitation.

In each plot, the rain collecting gauges were distributed in transects of eight different directions starting from the central tree and leading to the surrounding trees. The distance between measurement points was lm in four transect directions, and 2 m for the remaining four transects.

For the measurement of the soil water potential, we installed 455 tensiometers, 230 in the spruce dominated plot and 225 in the beech dominated plot.

5 tensiometers were installed at each sampling point, close to the rain-collecting gauge, at 5 different depths of 10 cm, 20 cm, 40 cm, 80 cm and 120 cm.

Figure 1 gives an idea on the distribution of the sampling points.

Simulation of soil water fluxes and budget calculations

We used the Hydrus-1D model to calculate one-dimensional (vertical) soil water flow and water budgets based on the simulated and measured flux rates. The model can simulate the water movement in unsaturated, partially saturated or fully saturated porous media (Simunek et al., 1998) by numerically solving the Richards equation for saturated – unsaturated water flow (van Genuchten and Simunek, 2000):

Among the input parameters is the soil water retention curve, which we experimentally determined in the laboratory employing a pressure/flow cell, the infiltration rate over time, the potential evapotranspiration, the relative root distribution, and root water uptake parameters describing to response of water uptake to soil water tension status. The output parameters comprise simulated soil water potentials, which are used for validating of the model, seepage output fluxes (over time and cumulated), change in soil water store and actual transpiration.

The root water uptake parameters influence the manner in which transpiration is reduced below potential when the soil is no longer capable of supplying the amount of water required by the plant under the prevailing climatic conditions. We used the Feddes model within our simulations (Feddes et al., 1978).

The potential evapotranspiration data used as model input were obtained by applying the Penman-Monteith equation.

For the simulation with Hydrus 1D, root water uptake is considered to be one-dimensional only. It is described by the "β function", a relative distribution of root uptake in the vertical soil profile. The β functions used in the model runs were calculated from the experimental root distribution obtained by (Villanueva, 2003) in a similar site near our experimental plots.

For a detailed description and discussion of the Hydrus-1D model application in this study, see (Cheussom, 2004).

RESULTS AND DISCUSSION

Differentiation of throughfall in dependence on local canopy cover

Several studies (Benecke, 1984; Eschner, 1967; Jackson, 2000; Weihe, 1984; Weihe, 1985) have demonstrated that considerable variability in throughfall may exist on a small spatial scale between points below tree canopies. We classified the total canopy area of the two plots into different local canopy cover classes, in order to describe the amount of throughfall in dependence of the local canopy coverage. Table 1 describes the differentiation of the four classes within forest (plus a reference set of points in open land). The sampling points of the two plots were assigned to these canopy classes according to their local canopy coverage (for the spruce dominated plot, this may be also inferred from Fig.1).

Table 1: Classification of four local canopy cover situations (plus open land).

Tab 2: Klassifikation von 4 lokalen Überschirmungssituationen.

No.	Canopy class	Area covered by	No. of sampling points
0	Open land	No cover, free sky	8
1	Gap	No local coverage above	4
2	Beech	Beech crown(s)	42
3	Beech - spruce	Beech and spruce crown (mixed cover)	30
4	Spruce	Spruce crown(s)	15

Figure 2 shows the differences of the cumulated rates of precipitation and throughfall in the different canopy classes, both in the vegetation seasons (summers of 2001 and 2002) and in the winter seasons.

During the vegetation seasons, the amounts of precipitation collected in the open land differed significantly ($p < 0.05$; Anova with Tukey test for differences of the means) from those of the canopy classes. The beech and the gap classes did not differ significantly from each other, but both the two differ from the beech-spruce and the spruce classes. The beech-spruce and the spruce classes did not differ statistically significant in their means (ANOVA with Tukey test at 0.05 sign. level).

During the winter season, all these differences observed in summer levelled out, and only a statistically significant difference remained between open land and the four canopy classes.

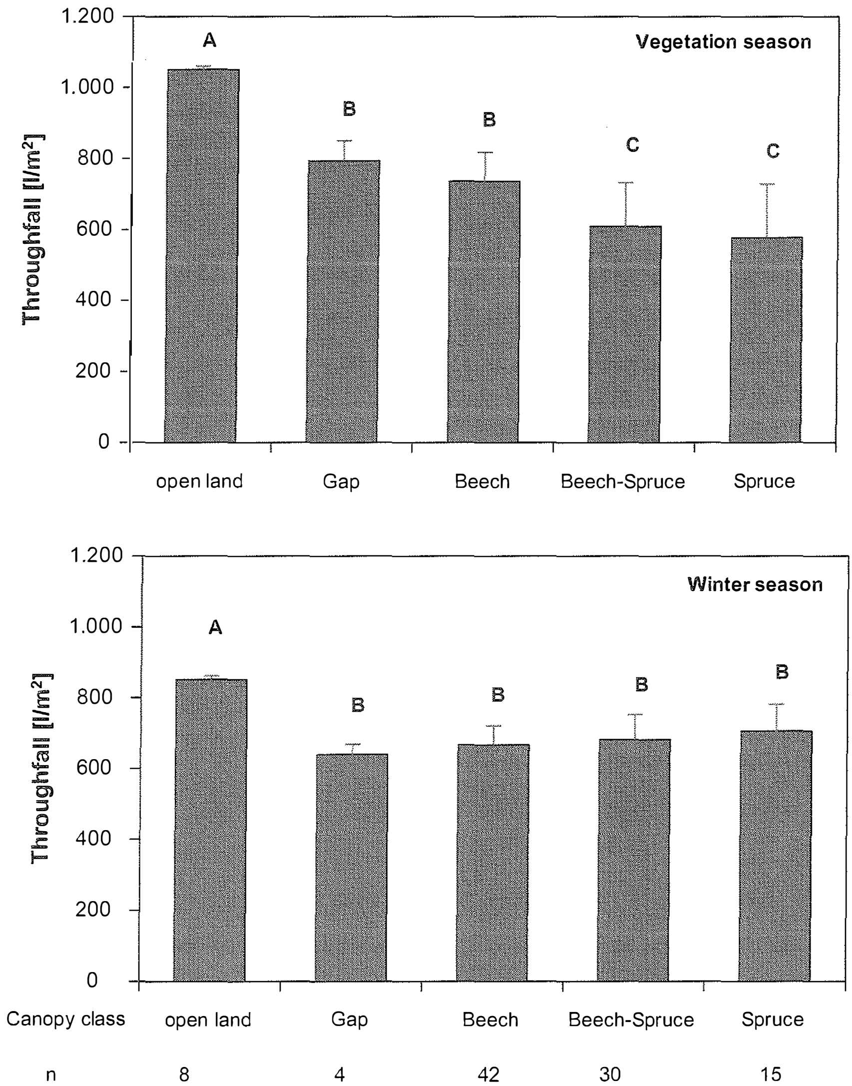


Fig. 2: Cumulative water flux rates in the open land and four canopy classes in the vegetation seasons (2001 plus 2002) and in the winter seasons (ANOVA with Tukey test at 0.05 sign. level).

Abb. 2: Kumulative Wasserflußraten im Freiland und den 4 Kronenklassen während der Vegetationsperiode (2001 plus 2002) und im Winter (ANOVA mit Tukey Test bei 5% Signifikanzniveau).

These results are counter-intuitive at first sight, because since the beech is defoliated in the winter time, one might expect an even sharper contrast between beech and spruce local cover then. However, the levelling off in flux rates between all the local cover classes in winter may be explained by a generally more random spatial distribution of throughfall, owing to the fact that much of the precipitation at a mountainous site like Solling is in the form of snow, which is easily blown off the canopy and distributed by wind in turbulences, which would tend to make the distribution to the ground (or to our samplers) rather random.

In terms of percentage of the gross precipitation (open land), the amounts of throughfall were 70%, 58% and 55% respectively for the beech, the beech-spruce and the spruce classes.
The differences in the amount of throughfall can be generally explained by the higher interception of Norway spruce in comparison to European beech trees. The interception as a percentage of gross precipitation reported in the literature ranges from 17% to 19% for beech stands and from 28% to 39% for spruce stands (Benecke, 1984; Rothe and Kreutzer, 1998; Viville et al., 1993). Since the interception of the spruce trees is higher than that of the beech trees, the amount of throughfall collected under beech canopy would be higher than the one collected under spruce canopy. The percentage of throughfall in terms of gross precipitation under the mixed beech-spruce canopy (58%) is an intermediate value between the beech (70%) and the spruce (55%) values, however, it is much closer to the lower value marked by the spruce cover. Hence, it seems that in a mixed canopy of beech and spruce, the influence of spruce with its high interception is disproportionately strong.

Differentiation of throughfall along transects

Figure 3 shows the distribution of the local cumulated throughfall along a transect between spruce F4, the beech central tree, and spruce F8 (see Fig. 1) for the vegetation season 2001 and the winter season 2001/02. The distance between each measurement point was 1m.
During the vegetation season (growing season) the smallest amounts of throughfall were collected on the transect points right next to the beech tree (10-12 which correspond to MP24 and MP23 in Fig. 1). The highest amounts of local throughfall were collected on the transect points which were in the middle between the beech and the spruce tree F4, where the canopy density arrived at a minimum, while distance to the next neighbouring trees attained a maximum. Interestingly, this pattern of local throughfall was shifted around during the winter season, when the smallest amounts were collected in the middle (points 4 and 5 which correspond to MP28 and MP27 in Fig. 1) of the transect between F4 and the beech central tree.

While the higher local flux rates around the beech central tree in winter can be explained by the defoliation of this dominating tree's big crown, the reversal of the pattern in the middle of the long part of the transect is less easy to elucidate, and may be again due to random effects in the throughfall distribution as snow in the wintertime.

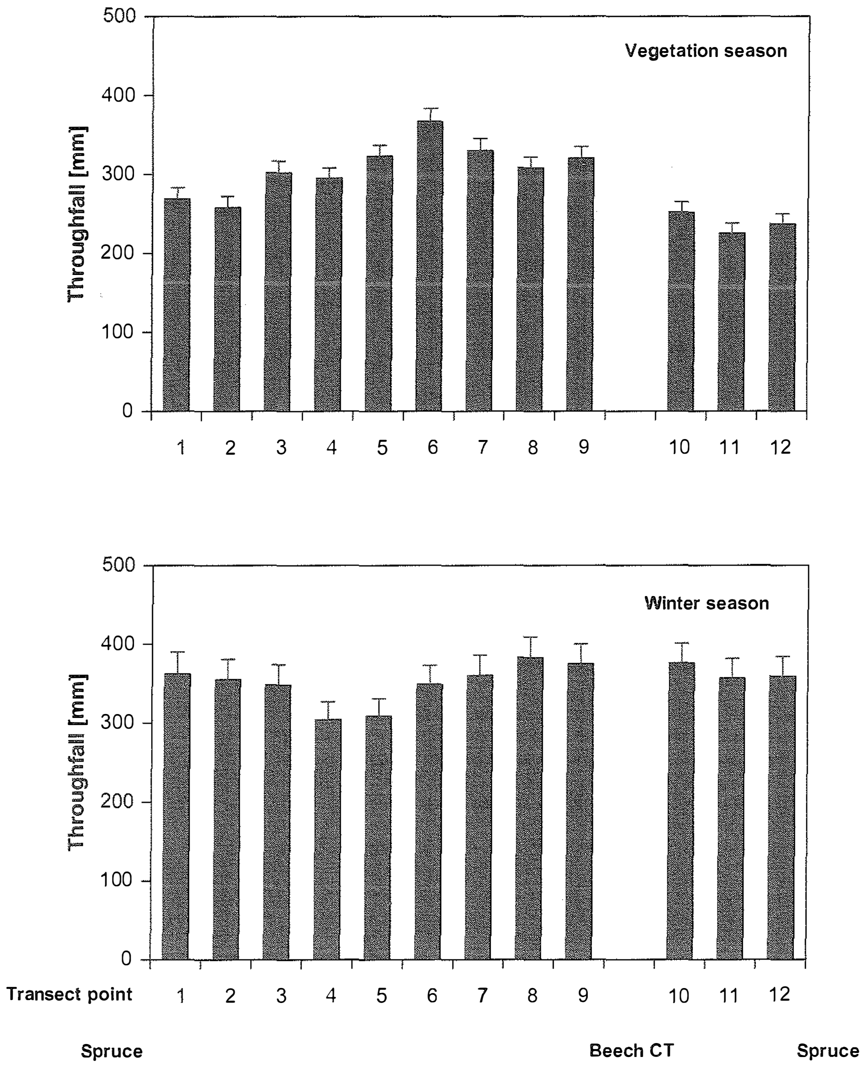


Fig. 3: Local throughfall (cumulative values) along a transect between the spruce tree number four (F4), beech central tree and spruce number eight (F8) in the spruce dominated plot for the vegetation season (10.05.01 to 25.10.01) and the winter season (21.01.02 to 02.05.02)

Abb. 3: Lokaler Niederschlag unter der Krone (kumulative Werte) entlang eines Transektes zwischen Fichte Nummer 4 (F4), dem Buchen-Zentralbaum und Fichte Nummer 8 (F8) im fichtendominierten Plot in der Vegetationsperiode (10.05.01 bis 25.10.01) und im Winter (21.01.02 bis 02.05.02)

Fine-root distribution of beech and spruce over a transect

A number of studies have demonstrated that root systems of spruce tend to be more shallow in mixed stands than in pure stands, while beech roots occupy the deeper soil horizons (Rothe and Kreutzer, 1998; Schmid and Kazda, 2000; Schmid, 2002; Schmid and Kazda, 2001; Schmid and Kazda, 2002; Villanueva, 2003). In general, the root distribution differs widely in dependence of the tree species considered (Heitz, 2000).

Figure 4 shows the distribution of the fine-root biomass (summarized from surface down to 40 cm depth) on the transect between spruce tree F4, the beech central tree and spruce F8. It can be seen that spruce has a higher total fine-root biomass in the uppermost 40 cm of the soil (1650 $kg\cdot ha^{-1}$ compared to 910 $kg\cdot ha^{-1}$ for beech). Beech fine-roots may occur in higher density than those of spruce at greater depths, although these data were not recorded in our study. Fine-roots of both tree species are well represented along the whole transect. One interesting observation is the presence of high densities of vital spruce fine-roots right next to the beech central tree. This pattern could be caused by the availability of large quantities of water running down the beech trunk as stemflow (Benecke, 1984). The beech tree has probably only coarse woody roots in this area, so the surrounding spruces can efficiently tap the concentrated infiltration flux generated by the stemflow on the beech. If this hypothesis is valid, the example would nicely demonstrate hydrological resource use optimisation in the mixed stand, as the spruce is recycling water from beech stemflow, which would otherwise be lost to deep percolation and seepage from the root zone.

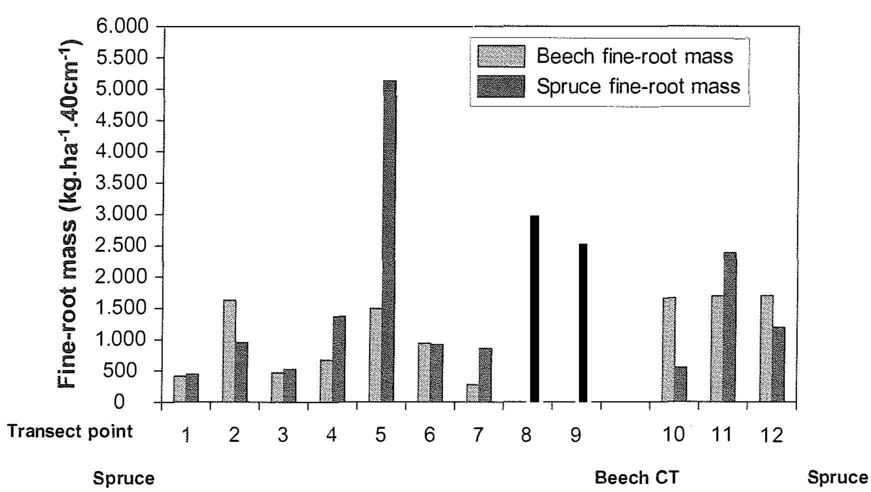


Fig. 4: Fine-root biomass along a transect.
Abb. 4: Feinwurzelmass entlang des Transektes.

Comparison of simulated water budgets between local cover classes

The results of the water fluxes- and budget calculations based on application of the one-dimensional simulation model Hydrus-1D are summarized in table 2. Separate simulation runs were performed for each of the canopy cover classes, based on their average hydrological input data, and validated against time series of measured soil water potentials in the different depths, where the tensiometers were installed. For a detailed presentation of all hydrological simulation results, see (Cheussom, 2004).

Table 2: Water balance components according to measurements and Hydrus-1D simulations for the different local canopy cover classes (May – October 2001).

Tab. 2: Komponenten der Wasserbilanz nach den Messungen und den Simulationen mit Hydrus-1D für verschiedene lokale Kronenüberschirmungsklassen (Mai – Oktober 2001)

Water balance component	Gap (n=4)	Beech (n=42)	Beech-spruce (n=30)	Spruce (n=15)
a: as absolute fluxes [mm]				
Bulk Precip.	523	523	523	523
Throughfall	384	350	282	268
Seepage output	151	92	52	48
b: as fluxes relative to bulk precipitation [%]				
Throughfall	73	67	54	51
Seepage output	29	18	10	9

The data in Tab. 2 refer to the summer season (growing season, May - October 2001). The gaps received the highest amount of local throughfall (384 mm) and also had the highest amounts of local simulated seepage water flux (151 mm), as could be expected.

Among the cover classes under canopy, the highest amount of throughfall (350 mm) was collected under the beech class, although the measurements entirely originate from the period when the beech has its leaves. Throughfall in the beech-spruce class (282 mm) was an intermediate value between that of the beech class and the spruce class (268 mm) and not the average value. It is in fact strongly shifted towards the pure spruce cover value, indicating that the high interception water loss (interception evaporation) of the spruce crowns is dominating the hydrological regime with respect to interception in the beech-spruce mixture.

The difference between the throughfall flux collected on the beech class and the one recorded in a pure beech forest (427 mm) during the vegetation season by (Benecke, 1984) at Solling is about 77 mm, and can be partly explained by the difference of the open land precipitation between the two studies. The amount of open land precipitation recorded by (Benecke, 1984) was 546 mm whereas we recorded 523 mm. In addition, we did not measure the flux rates of stemflow on the beech trees, which can contribute significantly (10-20%) to total throughfall under beech.

As would be expected, the simulated seepage output fluxes for the different canopy cover classes exhibit the same ranking as the input via throughfall, ranging from 29% of open land precipitation flux in the gap situation down to merely 9% thereof under spruce canopy cover. The values of pure spruce cover and mixed beech/spruce are very close and much lower than the one for the pure beech cover situation. Hence, it can be concluded that with respect to deep seepage generation and groundwater recharge, mixed stands of beech and spruce are not much more favourable than pure spruce stands, since the spruce canopy characteristics, particularly the high interception water loss, strongly seem to prevail in the mixed canopy. The interception of rainfall upon the spruce trees is higher than on beech trees because of the higher canopy storage capacities of spruce. (Benecke, 1984) found the canopy storage capacity to be 2.6 mm for a pure beech stand and 4.7 mm for pure spruce in the Solling forest. Smaller rainfall events may thus be completely intercepted by spruce canopy, while under beech cover throughfall generation would start much earlier, and less intercepted water would be re-evaporated to the atmosphere.

CONCLUSIONS

The results of this study illustrate in a number of facets that a tree species mixture brings about distinct, small-scale patterns of infiltration. Such patterns have to be known and regarded before assessment and modelling of water budgets in mixed forest at stand level.

Statistically significant differences in local throughfall between the different canopy cover classes in a mixed beech-spruce forest could be observed in summer, while these differences were obviously disappearing in winter, when the mean values could not be attributed statistically significant differences.

The findings support the central hypothesis that the water balance in mixed forest stands is different from the average value between the respective pure (mono-specific) stands. For the mixed cover sampling locations in our study, the hydrological input and modelled water budget characteristics are in fact very similar to the pure spruce cover locations, indicating that the spruce crowns exert a very strong influence in the mixed canopy. If this relationship observed in our study could be confirmed as a general feature, it would mean that little additional seepage outflow is generated when spruce monoculture forest is converted to mixed beech-spruce stands.

Hence, from a water resource point of view, mixed forest would not be much more favourable than monospecific forest.

From an ecological point of view, however, our results indicate that complementary rooting patterns may emerge in mixed stands, as we observed a local accumulation of spruce fine-roots next to the beech trunk, where spruce was obviously tapping the ample stemflow water flux of the beech. This is an indication of a resource use optimisation in the mixture, which may not be attained in pure stands.

However, it is not justified to generalize widely on the basis of the results of this single study, but more research work into the water relations of mixed stands should be initiated, in order to broaden and test the basis for generalizations.

ACKNOWLEDGEMENTS

We wish to express our gratitude to DAAD, the German Academic Exchange Service, for a doctoral grant supporting Levis Cheussom, and we thank Andreas Ibrom of the Institute of Bioclimatology, Göttingen University, for providing daily data of the potential evapotranspiration according to Monteith/Penman.

REFERENCES

Benecke P., 1984: Der Wasserumsatz eines Buchen-und eines Fichtenwaldökosystems im Hochsolling. J.D. Sauerländer's Verlag. Frankfurt am Main.

Cheussom L., 2004: Hydrological Pattern in a Mixed Forest of Northern Germany. Berichte des Forschungszentrums Waldökosysteme, Reihe A Band 187. Forschungszentrum Waldökosysteme der Universität Göttingen. Göttingen.

Eschner A.R., 1967: Interception and soil moisture distribution. Sopper W.E., Hull, H.W. (Eds.). Pergamon Press. Toronto.

Feddes R.A., Kowalik P.J. and Zarandny H., 1978: Simulation of field water use and crop yield, NY: John Wiley. New York.

Gravenhorst G.Z. and Szarejko Z., 1990: Das Klima des Sollings. Exkursionsführer Solling. Berichte des Forschungszentrums Waldökosysteme, **17**. 5-14. Forschungszentrum Waldökosysteme. Göttingen.

Heitz R., 2000: Reconversion of norway spruce (*Picea abies* (L.) Karst.) stands into mixed forests: effects on soil properties and nutrient fluxes. H. Hasenauer (Ed.): Proceedings of the International Conference on Forest Ecosystem Restoration. University of Agric. Sciences, Vienna.

Jackson N.A., 2000: Measured and modelled rainfall interception loss from an agroforestery system in Kenya. Agricultural and Forest meteorology **100**, 323-336.

NMELF Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Forsten, 1996: Waldentwicklung Solling. Fachgutachten. **5**, 9-39. Niedersächsisches Forstplanungsamt. Hannover.

Rothe A. and Kreutzer K., 1998: Wechselwirkungen zwischen Fichte und Buche im Mischbestand. AFZ / Der Wald **15**, 784-787.

Schmid I., 2002: The influence of soil type and interspecific competition on the fine root system of Norway spruce and European beech. Basic and Applied Ecology: **3**, 339-346.

Schmid I. and Kazda M., 2000: Root distribution of Norway spruce in pure stands and in mixtures with European beech. In: H. Hasenauer (Ed.): Proceedings of the International Conference on Forest Ecosystem Restoration, 241-246. University of Agric. Sciences, Vienna.

Schmid I. and Kazda M., 2001: Vertical distribution and radial growth of coarse roots in pure and mixed stands of fagus Sylvatica and Picea abies. Can. J. For. Res. **31**, 539-548.

Schmid I. and Kazda M., 2002: Root distribution of Norway spruce in monospecific and mixed stands on different soils. Forest Ecology and Management **159**, 37-47.

Simunek J., Sejna M. and van Genuchten M.Th., 1998: HYDRUS 1D, Software Package for Simulating One-Dimensional Movement of Water, Heat and Multiple Solutes in Variably Saturated-Media, Version 2.0. IGWMC - TPS-70, 1-178. Golden, CO 80401: Colorado School of Mines.

van Genuchten M.Th. and Simunek J., 2000: Advanced Modelling of Water Flow And Solute Transport. Variably-Saturated Media. Course notes, University of Hannover. Institute of Soil Science. Hannover

Villanueva I., 2003: Comparison of fine root distribution between pure and mixed stands of norway spuce (*Picea abies*) and european beech (*Fagus sylvatica).* University of Göttingen. pp.16-29. Master Thesis.

Viville D., Biron P., Granier A., Dambrine E. and Probst A., 1993: Interception in a mountainous declining spruce stand in the Strengbach catchment (Vosges, France). Journal of Hydrology **144**, 273-282.

Weihe J., 1984: Benetzung und Interzeption von Buchen-und Fichtenbeständen. IV. Die Verteilung des Regens unten Fichtenkronen. Allg. Forst- u. Jagdzeitung **155**, 241-252.

Weihe J., 1985: Benetzung und Interzeption von Buchen- und Fichtenbeständen V. Die Verteilung des Regens unter Buchenkronen. Allg. Forst- u. Jagdzeitung **156**, 81-89.

NITROGEN FLUX STUDIES IN THE NORTH TYROLEAN LIMESTONE ALPS

UNTERSUCHUNGEN DER STICKSTOFFFLÜSSE IN DEN NORDTIROLER KALKALPEN

Friedl HERMAN, Stefan SMIDT, Michael ENGLISCH, Robert JANDL

Federal Office and Research Centre for Forests, A-1130 Vienna, Seckendorff-Gudent Weg 8

ABSTRACT

At the study area Mühleggerköpfl, a forest ecosystem on calcareous bedrock, major pathways of nitrogen were investigated. The main goals were to quantify the nitrogen pools in above-ground and below-ground compartments and the rates of nitrogen input, turnover, and output. Basing on a multitude of continuous and discontinuous field measurements, model calculations were done. Although nitrogen input exceeded the Critical Loads of the WHO, needle analyses indicated nitrogen deficiency and nutrient imbalances. The atmospheric input of inorganic nitrogen was higher than the outflux below 50 cm soil depth. Nitrogen was emitted mostly as N_2 and as only small amounts of N_2O. A ^{15}N tracer experiment showed that about 50% of the applied nitrate were discharged into the groundwater and 50% were microbiologically processed in the soil. The conclusion is, that nitrogen is retained in the system and that the site is not yet saturated. The results of field measurements were confirmed by simulation models.

KEYWORDS: Nitrogen pools, nitrogen fluxes, nitrogen output, internal fluxes, modelling, Limestone Alps

ZUSAMMENFASSUNG

Am Mühleggerköpfl, einem Waldökosystem auf Karbonatgestein, wurden die wichtigsten Stickstoffflüsse untersucht. Die Ziele der Arbeit waren die Quantifizierung der Stickstoff-Pools in der ober- und unterirdische Biomasse und die Raten des Eintrages, der Umsetzung und des Austrages von Stickstoff. Modellberechnungen wurden auf der Grundlage von zahlreichen kontinuierlichen und diskreten Erhebungen im Gelände durchgeführt. Obwohl der Stickstoffeintrag die kritische Ladung nach WHO-Kriterien übersteigt, zeigen die Nadelanalysen Stickstoffmangel und Nährstoffimbalanzen an. Der Eintrag von anorganischen Stickstoff aus der Atmosphäre überstieg den Austrag aus 50 cm Bodentiefe. Für die Stickstoffemission war hauptsächlich N2 und im untergeordneten Maße N2O verantwortlich. Ein 15N-Tracerversuch zeigte, dass etwa 50% des aufgebrachten Nitrates ins Grundwasser gelangte und 50% im Boden mikrobiologisch umgesetzt wurden. Daraus wurde der Schluss gezogen, dass Stickstoff im System zurückgehalten wird und dass der Standort noch nicht stickstoffgesättigt ist. Diese Ergebnisse wurden von Simulationsmodellen unterstützt.

SCHLÜSSELWORTE: Stickstoff pools, Stickstoffflüsse, Stickstoffverlust, interne Stoffflüsse, Modellierung, Kalkalpen.

INTRODUCTION

During the last decades, the problem of excess atmospheric nitrogen input as a factor of destabilisation of forest ecosystems was given high priority in European research projects. The results of these projects were subject to a controversial discussion (e.g. Wright & Tietema, 1995; Binkley & Högberg, 1997; Kreutzer et al., 1998; Feger & Raspe, 2000). For centuries, forest ecosystems in various parts of Central Europe have lost considerable quantities of nutrients due to traditional forest management practices (litter removal, pollarding and forest pasture). The removal of easily mineralizable organic matter led to a large-scale nitrogen deficiency (Ebermayr, 1876; Kreutzer, 1972; Englisch, 1992; Smidt et al., 2002). The global increase of nitrogen emissions noted since the beginning of the industrial age (Galloway, 1998) caused excess nitrogen depositions in large areas of Europe (Kölling, 1991; Ortloff & Schläpfer, 1996; Bundesforschungsanstalt für Forst- und Holzwirtschaft, 1997). In order to assess the risk caused by nitrogen input intensive research work has been conducted to study nitrogen cycles in forest ecosystems (e.g. Matzner, 1988; van der Hoek et al., 1998; Wright & Rasmussen, 1998; Schulze 2000; Herman et al., 2002).

Since the beginning of the 80ies, the Federal Office and Research Centre for Forests has conducted interdisciplinary research projects in the field to describe the response of trees to the environmental situation. The research activities in the Austrian Alps (Zillertal altitude profile and Achenkirch altitude profiles/Tyrol, Bodental/Carinthia) are aimed at improving the knowledge of potential natural and anthropogenic stress factors to forest ecosystems. In cooperation with numerous university institutes and research centers, causal relationships between stressors and their effects on mature trees and on the ecosystem were described (Smidt et al., 1995, 1996; Herman et al., 1998; Smidt & Herman, 2004).

In one of the current studies the nitrogen input and output situation in a well documented area in the North Tyrolean Limestone Alps is investigated. Litter raking and pollarding activities during decades have been responsible for the poor nutrition supply of the local forests (Englisch, 2001). As a consequence, the results of crown assessments indicate a high percentage of needle loss (Gärtner, 2001). Needles are suffering from lack of nutrients (Stefan & Fürst, 1998), most frequently from nitrogen deficiency. The results of several years of field measurements, (Kalina et al., 1998; Smidt, 1998) as well as risk assessment mapping and modelling (Knoflacher & Loibl, 1998) identified nitrogen input exceeding Critical Loads.

For the quantification of the site water balance and nitrogen dynamics in different spatial and temporal scales, the following subsystems have been considered:

- **Input:** Open field and throughfall deposition (wet, dry and occult deposition), canopy uptake.
- **Pools:** Above-ground biomass (spruce), organic and inorganic nitrogen in the soil, soil water, nitrogen content of the soil water.
- **Internal fluxes:** Litterfall, surface runoff, soil water and nitrate relocation, net mineralization rate, nitrate fluxes / stable isotopes, absorbable nitrogen.
- **Output:** Nitrate fluxes into the subsoil and N_2O emission rates.

MATERIAL AND METHODS

The study area and the growth areas of Austria

The study area (Fig. 1) is located in the North Tyrolean Limestone Alps, growth area 4.1 (Kilian et al., 1994).

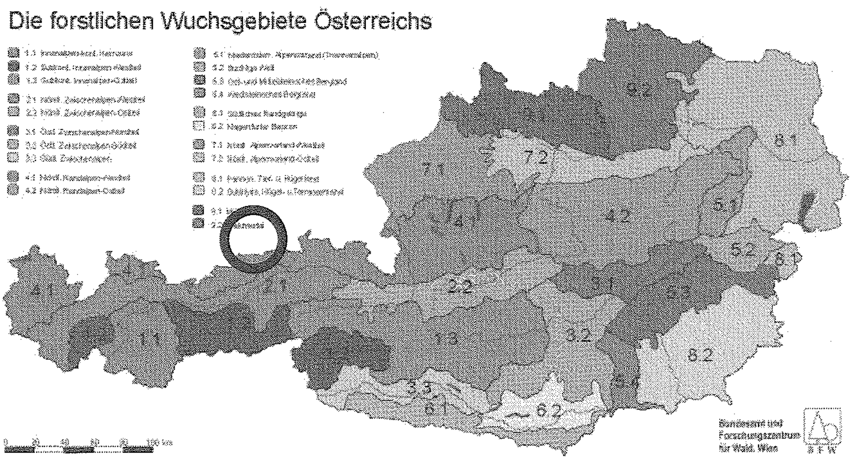


Fig. 1: Location of the study area (circle) and the growth areas of Austria (Kilian et. al., 1994).

Abb. 1: Lage des Untersuchungsgebietes (Kreis) und die Wuchsräume von Österreich (Kilian et. al., 1994).

The study plot at the Mühleggerköpfl

The Mühleggerköpfl is located west of the former customs station Achenpass. It is an isolated hill peaking 120 m above the valley, consisting of dolomite. The small mountain ridge shows a

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 154-168

ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) *ISBN 3-900865-17-5*

small-scale pattern of various silvicultural management types. The stands around the summit plateau are specially exposed. Some characteristics are shown in Tab 1.

With respect to ecological factors, the Mühleggerköpfl may be considered as typical for the growth area 4.1. The 125-year-old stand is dominated by Norway spruce and the stand is interspersed with red pine and beech, growing isolated or in groups (Englisch, 2001)., the naturalness is classified with 4.5 (moderately to strongly altered (Grabherr et al., 1997)). *Picea abies* shows a dominant height of 27.1 m, a basal area of 40 m^2 $ha^{-1}$and a growing stock of 548 m^3 ha^{-1}, which corresponds to yield class 6 (yield table for spruce, Bavaria).

Tab. 1: Characteristics of the intensive investigation plot.

Tab. 1: Eigenschaften der Intensivbeobachtungsflächen.

Coordinates	**11° 38‘ 21“ East; 47° 34‘ 50“ North**
Location	Karwendel mountains/Tyrol
Tree species composition	approx. 90% spruce, 10% beech
Area	ca. 1/3 ha
m a.s.l.	920 m
Soil	Rendzic Leptosol / Chromic Cambisol

For the summit area, the dominant height is 19.1 m, the basal area is 20 m^2 ha^{-1}, and the growing stock is 156 m^3 ha^{-1}, which corresponds to yield class 2.5 (Marschall, 1975). N-stocks are high, while close C/N ratios (16–18) suggest favourable transformation conditions for N-mineralisation and nitrification. The carbonate content of the soil is extremely high and marked by the presence of dolomite (Mutsch, 2001).

Measurement facilities and parameters

The measurement facilities and parameters, which form the basis for the calculation and modelling of the element budgets, are indicated in Figure 2 and Table 2.

Figure 2 shows the study plot and the measuring facilities. Table 2 summarizes all the equipment including the containers C1 and C2. They are located in the vicinity of the intensive study plot. Most of the results refer to the measurement period 1998-2000; other periods are pointed out. The applied methods and techniques are described in detail in Smidt et al. (2002).

Modelling

The transpiration of the forest and the evaporation was estimated with the forest hydrological model Brook-90 which uses the Penman-Monteith equation (Federer, 1995). Input parameters were the daily precipitation, air temperature (minima, maxima, mean values), the water saturation deficit of the atmosphere and wind velocity. The structure of the forest was represented in a site specific set of parameters. Soil hydrology was simulated with Hydrus 2-D (Simunek et al., 1998). Input parameters were the daily precipitation below the canopy (measured, calculated), the daily transpiration and evaporation (simulated with Brook-90), and the soil texture. Hydrus yields a continuous record of the soil water content in predefined soil layers and the soil water fluxes in a high temporal resolution. The assumptions and the calculations were described in detail by Jandl et al. (2002).

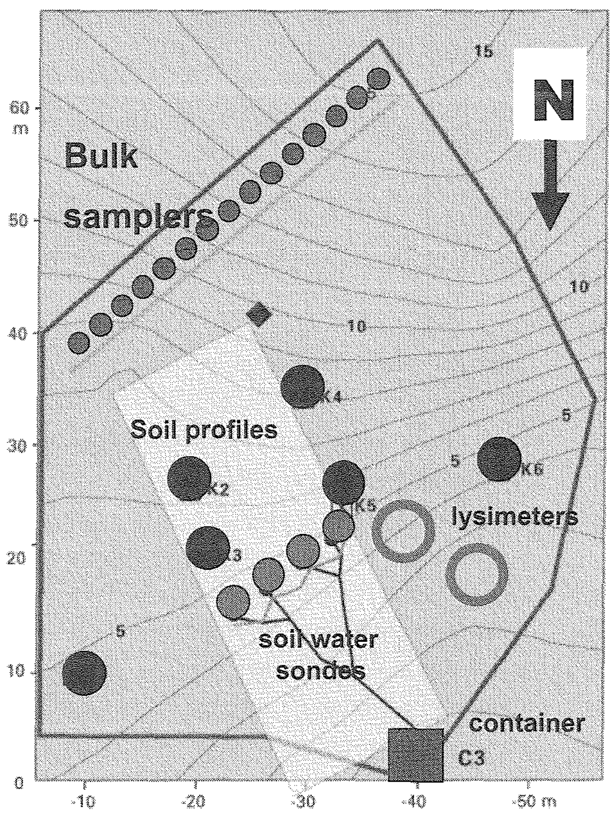


Figure 2: The study plot and measurement facilities at the Mühleggerköpfl.

Abb. 2: Untersuchungsplot und Meßeinrichtungen am Mühleggerköpfl.

Table 2: Measurement facilities and parameters (Ions: Cl^-, NO_3^-, SO_4^{--}, NH_4^+, Na^+, K^+, Ca^{++}, Mg^{++}); nitrate-isotope relationship ($^{15}N/^{14}N$-ratio, $^{18}O/^{16}O$-ratio); meteorological parameters (temperature, air humidity, radiation, wind direction, wind velocity, air pressure).

Tab. 2: Meßeinrichtungen und Meßparameter am Mühleggerköpfl.

Measurement device		**Parameters**
Container C 1	Fog sampler	pH, conductivity, ions; nitrate-isotope relationships in occult deposition
	Passive samplers	SO_2, NO_2, NH_3 in dry deposition
	Stack filters	HNO_3, SO_4^{2-}, NO_3^-, NH_4^+-aerosol, Na^+, K^+, Ca^{++}, Mg^{++} in dry deposition
	WADOS	Quantity, pH, conductivity, ions; nitrate-isotope relationships in wet depo.
Container C 2		SO_2, NO, NO_2, O_3; meteorological parameters
3 bulk-open field collectors		Quantity, pH, conductivity, ions, nitrate-isotope relationships in wet deposition
15 crown throughfall-bulk collector		Quantity, pH, conductivity, ions; $^{15}NO_3$-N in wet deposition
1 hydrometeorological station		Meteorological parameters incl. evaporation, water temperature close to the surface, snow depth
32 gypsum blocks		Soil water content
6 Theta sondes		Soil water content
10 Vitel sondes		Soil water content, soil temperature
16 suction cups (soil solution)		Quantity, pH, conductivity, ions; nitrate-isotope relationships
3 surface runoff troughs with 2 collection vessels		Quantity, pH, conductivity, ions; nitrate-isotope relationships
6 gas measuring chambers		N_2O , CO_2, CH_4
18 ion exchanger		NO_3^-- and NH_4^+-leaching, N gross mineralisation
24 soil samples		NO_3^- and NH_4^+- concentration, N net mineralisation, N in microbial biomass, extractable glucose equivalents, gravimetric water content
18 observation plots		Litterfall and decomposition velocity
Forest lysimeter		Nitrate-isotope relationships; 2 ^{15}N-applications: Incorporation of $^{15}NO_3$-N into microbial biomass, roots, sprouts of ground vegetation, soil fauna; $^{15}NO_3^-$-output from depth 0-10 cm and denitrification as $^{15}N_2O$
Snow lysimeter		Nitrate-isotope relationships
Container C 3		Data logging and sample collection (soil-related data)
Soil samples (4 profiles)		Dry mass, pH (H_2O), pH ($CaCl_2$), CO_3^{2-}, $C_{org.}$, $N_{ges.}$, C/N, humus content; P, K, Ca, Mg, Fe in the acid extract; K, Ca, Mg in the $BaCl_2$-extract; Cl^-, NO_2^-, NO_3^-, SO_4^{2-} in the water extract; nitrate-isotope relationships
4 litter collectors		N in litter

RESULTS AND DISCUSSION

Input

Open field and throughfall deposition

The nitrogen input (bulk deposition) ranged from 11 to 15 kg ha^{-1} a^{-1}. This input was moderate compared to other alpine areas with an input up to 30 kg ha^{-1} a^{-1} (Smidt, 2002).

The sum of wet, dry and occult nitrogen deposition was approximately 17 kg ha^{-1} a^{-1} (Kalina, 1997; Kalina et al., 2002). Therefore, the Critical Load of the WHO (2000: 15-20 kg N ha^{-1} a^{-1} for "calcareous forests") was exceeded.

The NO_3-N-input under the canopy (throughfall) was almost the same as the input in the open field. On the other hand, the input of NH_4-N under the canopy was about 1 kg ha^{-1} a^{-1} lower than in the open field; this quantity is therefore an approximation for the canopy uptake of NH_4-N.

Pools

Above-ground biomass

The mass of the above-ground biomass (t dry matter ha^{-1}) was determined in three 125-year-old Norway spruce trees. The results for the compartments wood, bark, branches, twigs and needles as well as the biomass allocation are given in Table 4. The mean annual nitrogen uptake of above-ground biomass was estimated on the basis of forest management tables (Marschall, 1975) and studies by Krapfenbauer & Buchleitner (1981). The present study does not take into account the below-ground biomass, which is around 20 % of the above-ground biomass in Norway spruce (Raspe, 1988).

The needles of the Norway spruce were classified as "nitrogen deficient" according to the thresholds for the nutrition status (Gussone, 1964). The N/P, N/Mg and N/K quotients were generally far outside the harmonious range (Hüttl, 1985).

Nitrogen in the soil

Total nitrogen: The mean total nitrogen pool to a soil depth of 40 cm was 15.500 kg ha^{-1}. The range of 4.600 kg between the highest and the lowest value of the 4 soil profiles is an indication for the inhomogeneity of the soil; these values were far above the Austrian average (8.200 kg). Around two thirds of the nitrogen pool was located in the upper 15 cm. The annual input was around 0.1 % of the pool (Mutsch, 2001). The soil microbial biomass contained 250 kg N ha^{-1}.

KCl-extractable nitrogen up to a soil depth of 10 cm amounted to 10 kg $ha^{-1}a^{-1}$ NH_4-N and 1.2 kg $ha^{-1}a^{-1}$ NO_3-N. Ammonium is fixed to the clay-humus-complex and remains immobile, nitrate remains in the soil solution.

Soil water

The estimated water quantities stored within 0-50 cm were between 105 and 230 mm. The range in the soil water pool was 40 to 90 mm and can be explained by the quick compensation of the water loss (evapotranspiration and percolation) by precipitation (Feichtinger et al., 2002).

Nitrogen content of the soil water

The mean NO_3-N concentration increased markedly from the precipitation samples to the surface runoff samples and to the soil water samples (50 cm depth), respectively. Contrary, the NH_4-N-concentrations were highest in the surface runoff (1.2 mg L^{-1} on the average) and lowest (near 0) in the soil water samples due to root uptake and nitrification. The NH_4 quantities in the soil water did not contribute to the nitrogen budget. The nitrogen quantities in the surface runoff which are carried with surface runoff (0.1% of the annual precipitation) are negligible. The strong increase of the NO_3:NH_4 ratio between field- / throughfall- precipitation and the soil water (Table 3) indicated a strong activity of nitrifying micro-organisms. Similar results were reported by Tietema (1998); sites which showed nitrate leaching after nitrogen input were characterized by high nitrification rates and a minimum of microbial nitrate immobilization. The threshold value for drinking water was not exceeded.

Table 3: Nitrogen concentrations and concentration ratios of the open field deposition, throughfall, surface water and soil water (average 1998-2000).

Tab 3: Stickstoffkonzentrationen und Verhältnisse der Konzentrationen im Freilandniederschlag, dem Niederschlag unter dem Kronendach, dem Oberflächenwasser und dem Bodenwasser (Mittelwerte 1998-2000).

	mg NO_3-N L^{-1}	mg NH_4-N L^{-1}	NO_3N/NH_4N
Open field deposition	0.32	0.36	0.89
Throughfall	0.43	0.36	1.19
Surface water	3.91	1.01	3.87
Soil water (50cm depth)	8.50	0.10	14.8

Internal fluxes

Litterfall

The results refer to the measuring period July to November 1999 and showed a nitrogen input of 21.6 kg ha^{-1} a^{-1} when related to one year.

Surface runoff, soil water and nitrate movement

The annual quantity of surface runoff was generally below 0.5 mm, thus amounting to 0.1 % of the annual precipitation. However, percolation into the subsoil amounting to ~58 % and evaporation amounting to ~42 % of the annual precipitation represented the main water fluxes These water dynamics determine to a great extent the nitrogen output (Feichtinger et al., 2002).

Net mineralization rate

14 kg N ha^{-1} a^{-1} were mineralized by net ammonification which was high in summer with low microbial nitrogen immobilisation at high soil temperatures, as well as shortly after litterfall. 13 kg N $ha^{-1}a^{-1}$ were nitrified, which, considering the ammonification rate, indicated complete nitrification. 36.5 kg NO_3-N ha^{-1} were accumulated during one vegetation period on ion exchange resin bags which were positioned at a soil depth of 10 cm (Zechmeister-Boltenstern et al., 2002). This pool can be interpreted as root-available (Härtel et al., 2002). No clear driving factors for nitrification were detected. The available NH_4 pool was 1.8 kg N ha^{-1}. Nitrate accumulation on ion exchange resin bags was three times as high as net nitrification. This means that this nitrate cannot be immobilised any more. The high rates of nitrate on ion exchange resins indicated that gross nitrification is much higher than net nitrification. Similar results were described from studies in undisturbed coniferous forests (Stark & Hart, 1997).

Nitrate fluxes / determination of the origin of nitrate in the soil water with stable isotopes

A comparison of ^{15}N:^{14}N-ratios in the bulk samples and surface water outlined that a low percentage of the nitrate in the surface water stems from precipitation, and the higher percentage from the mineralization processes in the humus layer. This interpretation was based on the similarity of the isotope ratios in the surface and soil water nitrate to the isotope ratios in precipitation and surface water. The findings were confirmed by the ^{18}O:^{16}O ratios. This ratio detected in precipitation samples is significantly different from the ratio in nitrate that developed from nitrification processes in the soil (Mayer & Bollwerk 2000). Therefore, the comparison of

^{18}O:^{16}O ratios of nitrate in the soil with nitrate in the deposition showed clearly that in most cases nitrate in the soil water stems from microbial conversion processes, and only to a small extent from atmospheric nitrogen input (Haberhauer et al., 2002).

Tracer experiment: In June 1998, nitrate was applied in the form of stable ^{15}N-isotopes to the forest lysimeter in order to quantify the leaching behaviour of nitrate migrating from the organic layer into deeper soil layers. The analysis of the soil water in the following 130 days showed, that more than 50 % of the applied nitrate was leached (Haberhauer et al., 2002).

Absorbable nitrogen

The total nitrogen pool of the soil contained only to a minor extent plant-available ammonium and nitrate. The nitrogen mineralization rates were high compared to the input. The NO_3 turnover in the upper soil measured by means of ion exchange resins was larger than the NH_4 turnover close to the upper layer. The extractable mineral-N (11 kg N $ha^{-1}a^{-1}$) was generally represented by NH_4-N (Härtel et al., 2002).

Output

Nitrate fluxes into the subsoil

The nitrogen output into the subsoil was calculated by means of the models UNSATCHEM and Hydrus-1D was 4-10 kg NO_3-N ha^{-1} a^{-1} (Jandl et al. 2002). Generally, nitrogen output was observed when input exeeded 10 kg ha^{-1} a^{-1} (Block, 1994; Dise and Wright, 1995; Wright & Tietema, 1995; Nilsson et al., 1998, Tietema et al., 1999). Below a threshold value of input of 9 kg N $ha^{-1}a^{-1}$ only minor output could be identified. The critical value above which nitrogen output was measured in all cases was around 25 kg $ha^{-1}a^{-1}$. This allows the conclusion that the study plot has still a considerable potential for nitrogen storage, what is also suggested by stochastic modelling.

N_2O emission

From May 1998 to October 1999 the N_2O-production amounted to 0.9 kg N_2O-N ha^{-1} a^{-1}. Seasonal variations of N_2O emissions depended on temperature, ammonium content of the soil, nitrate availability and soil respiration. High values were measured in spring and after rainfall. The emitted N_2O-N was less than 8 % of the input or 2-3 % of the mineralized nitrogen (Härtel et al., 2002). These quantities were rather low compared to other European forest stands (Butterbach-Bahl et al., 1997, 1998). The dominant form of N emissions was N_2, and only a minor amount of N_2O was produced. At this calcareous site in Tyrol nitrification plays probably a more important role in gaseous nitrogen losses compared to other sites in Austria on acidic bedrock (Hahn et al., 2000; Härtel et al., 2002). In Table 4, the main input, pools, internal fluxes and output data are summarized.

Table 4: Input, pools, internal fluxes and output of nitrogen at the study plot at the Mühleggerköpfl
Tab.4: Eintrag, Vorräte, interne Flüsse und Austrag von Stickstoff am Mühleggerköpfl.

		Fluxes (kg N ha^{-1} a^{-1})	**Pools (kg N ha^{-1})**
Input	Open field deposition	wet: 11-15 (12), dry: 2, occult: <1	
	Throughfall deposition	12	
	Canopy uptake (NH_4-N)	1.0	
Pools	Total above-ground biomass		572.5
	Wood		162.2
	Bark		69.1
	Branches		59.8
	Twigs		105.5
	Needles		176.0
	Biomass allocation	5.1	
	Microbial biomass		250
	Total N in the soil		15,500
	NH_4-N in the soil		10
	NO_3-N in the soil		1.2
	Plant-available N (0-10 cm)		36.5
	Extractable mineral N		11
Internal fluxes	Litterfall	22	
	Runoff	approx. 0	
	Tree uptake	available NH_4: 2 available NO_3: 37	
	Mineralisation	nitrification: 13 ammonification: 14	
Output	N_2O-emission	0.9	
	Total nitrogen loss (gaseous)	2 - 4	
	Deep percolation	4 - 10	

Based on the input and output data and according to the scheme of the Bundesministerium für Ernährung, Landwirtschaft und Forsten (2000), the investigation site can be classified as non-saturated or saturated at a low level, respectively (Table 5).

Tab. 5: Characteristic values of the nitrogen status of the ecosystem balance (Bundesministerium für Ernährung, Landwirtschaft und Forsten, 2000).

Tab. 5: Charakteristische Werte des Stickstoffstatus in Ökosystembilanzen (Bundesministerium für Ernährung, Landwirtschaft und Forsten, 2000).

Output (kg ha^{-1} a^{-1})	Input (kg ha^{-1} a^{-1})	Output / input	Nitrogen status
< 5	< 25	≤ 1	Not saturated
5 - 15	5 – 35	≤ 1	Saturation at a low level
> 15	> 15	≤ 1	Saturation at a high level
		> 1	N-release (disturbance)

CONCLUSIONS

In the study area the nitrogen deposition rates exceeded the Critical Load for "calcareous forests" and therefore indicate possible changes of the ecosystem. A large part of the deposited N is lost in the aqueous or organic phase. The process of denitrification goes nearly to completion. Needle analyses on the one hand and the relation between input and output confirm the fact that the system is able to accumulate further nitrogen input and is not yet saturated. When the nitrogen deposition continues at the present rate, the system will approach saturation. Given that the site is typical for the North Tyrolean Limestone Alps, nitrogen eutrophication may be expected to become a regional problem.

LITERATURE

Binkley D., Högberg P.: 1997: Does atmospheric deposition of nitrogen threaten Swedish forests? Forest Ecology and Management **92**, 119-152.

Block J., 1994: Stickstoffausträge mit dem Sickerwasser aus Waldökosystemen. IMA-Querschnittsseminar „Wirkungskomplex Stickstoff und Wald", Umweltbundesamt 21./22. 11. 1994. Texte 28/95.80-96.

Bundesforschungsanstalt für Forst- und Holzwirtschaft; 1997: Der Waldzustand in Europa. UN/ECE und EC, Genf und Brüssel.

Bundesministerium für Ernährung, Landwirtschaft und Forsten (BML), 2000: Kennwerte zur Charakterisierung des ökochemischen Bodenzustandes und des Gefährdungspotentials durch Bodenversauerung und Stickstoffsättigung an Level II Waldökosystem-Dauerbeobachtungsflächen. Arbeitskreis C der Bund-Länder Arbeitsgruppe Level II. Bundesministerium für Ernährung, Landwirtschaft und Forsten (BML).

Butterbach-Bahl K., Gasche R., Breuer L., Papen H., 1997: Fluxes of NO and N_2O from temperate forest soil: impact of forest type, N deposition and of liming on the NO and N_2O emissions. Nutr. Cycl. Agroecosyst. **48,** 79-90.

Butterbach-Bahl K., Gasche R., Huber C.H., Kreutzer K., Papen H., 1998: Impact of N-input by wet deposition on N-trace gas fluxes and CH_4-oxidation in spruce forest ecosystems of the temperate zone in Europe. Atmos. Environ. **32**, 559-564.

Dise N.B., Wright R.F., 1995: Nitrogen leaching from European forest in relation to nitrogen deposition. Forest Ecology and Management **71 (1-2)**, 153-161.

Ebermayer E., 1876: Die gesammte Lehre von der Waldstreu mit Rücksicht auf die chemische Statik des Waldbaues. Springer, Berlin.

Englisch M.; 1992: Standörtliche Grundlagen im Bereich der Höhenprofile Achenkirch. FBVA-Berichte **70**, 13-18.

Englisch M., 2001: Standorts- und bodenkundliche Eigenschaften der Intensivuntersuchungsfläche Mühleggerköpfl / Nordtiroler Kalkalpen. FBVA-Berichte **119**, 21-32.

Feger K.H., Raspe S., 2000: Verbundprojekt ARINUS im Schwarzwald: Auswirkungen von atmogenen Einträgen und Rehabilitierungsmaßnahmen auf den Wasser- und Nährstoffhaushalt von Fichtenwäldern. Handbuch der Umweltwissenschaften, 6. Erg.Lfg. **7/00**, 3-56.

Federer C.A., 1995: Brook 90 – A simulation model for evaporation, soil water, and steanflow. Version 3.1, PO Box 640, Durham NH.

Feichtinger F., Smidt S., Klaghofer E., 2002: Water and Nfluxes at a forest site in the North Tyrolean Limestone Alps. Environmental Science and Pollution Research, Special Issue **2**, 31-36.

Gärtner M., 2001: Terrestrische Kronenbeurteilung am Mühleggerköpfl in den Nordtiroler Kalkalpen. FBVA-Berichte **119**, 17-20.

Galloway J.N., 1998: The global nitrogen cycle: changes and consequences. Environmental Pollution **102** , 15-26.

Grabherr G., Koch G., Kirchmeir H., Reiter K., 1997: Hemerobie österreichischer Waldökosysteme. ÖAW-Veröffentlichungen des österreichischen MaB-Programmes, 17. Universitätsverlag Wagner, Innsbruck.

Gussone H.A., 1964: Faustzahlen für die Düngung im Walde. BLV Bayerischer Landwirtschaftsverlag, München.

Haberhauer G., Gerzabek M., Krenn A., 2002: Nitrate dynamics at an Alpine forest site (Mühleggerköpfl): O and N stable isotope analysis in natural water samples. Environmental Science and Pollution Research Special Issue **2**, 37-41.

Hahn M., Gartner K., Zechmeister-Boltenstern S., 2000: Greenhouse gas emissions (N_2O, CO_2 and CH_4) from three forest soils near Vienna (Austria) with different water and nitrogen regimes. Die Bodenkultur **51**, 115-125.

Härtel E., Zechmeister-Boltenstern S., Gerzabek M., 2002: Gaseous N losses from a forest site in the North Tyrolean Limestone Alps. Environmental Science and Pollution Research, Special Issue **2**, 23-30.

Herman F., Lütz C., Smidt S. (eds.), 1998: Description and evaluation of stress to mountain forest ecosystems: Results of long-term field experiments. Environmental Science and Pollution Research, Special Issue 1.

Herman F., Smidt S., Englisch M., Feichtinger F., Gerzabek M., Haberhauer G., Jandl R., Kalina M., Zechmeister-Boltenstern S., 2002: Investigations of nitrogen fluxes and pools on a Limestone site in the Alps. Environmental Science and Pollution Research, Special Issue **2**, 46-52.

Hüttl R.F., 1985: „Neuartige“ Waldschäden und Nährelementversorgung von Fichtenbeständen (Picea abies L.) in Südwestdeutschland. Freiburger Bodenkundl. Abh. 16.

Jandl R., Spögler H., Simuneck J., Heng L.K., 2002: Simulation of soil hydrology and establishment of a nitrogen budget of a mountain forest. Environmental Science and Pollution Research, Special Issue **2**, 42-45.

Kalina M., 1997: Atmosphärischer Eintrag von N- und S-Verbindungen durch trockene, nasse und okkulte Deposition im Höhenprofil Achenkirch. Dissertation Technische Universität Wien.

Kalina M., Zambo E., Puxbaum H., 1998: Assessment of wet, dry and occult deposition of sulphur and nitrogen at an Alpine site. Environmental Science and Pollution Research, Special Issue **1**, 53-58.

Kalina M.F., Stopper S., Zambo E., Puxbaum H., 2002: Altitude-dependent wet, dry and occult nitrogen deposition in an Alpine region (Achenkirch, Austria, 920-1758 m a.s.l.). Environmental Science and Pollution Research, Special Issue **2**, 16-22.

Kilian W., Müller F. & Starlinger F., 1994: Die forstlichen Wuchsgebiete Österreichs. FBVA-Berichte 82 (Wien).

Knoflacher M., Loibl W., 1998: Calculating and mapping of Critical Loads for protons and nitrogen on forest ecosystems in the Northern Tyrolean Limestone Alps. Environmental Science and Pollution Research, Special Issue **1**, 75-80.

Kölling C., 1991: Stickstoffsättigung von Waldökosystemen. Allg. Forstztg. **10**, 513-517.

Krapfenbauer A., Buchleitner E., 1981: Holznutzung, Biomasse und Nährstoffaustrag. Nährstoffbilanz eines Fichtenbestandes. Cbl. ges. Forstw. **98**, 193-223.

Kreutzer K., 1972: Einfluss der Streunutzung auf den Stickstoffhaushalt von Kiefernbeständen. Forstw. CBl. **91**, 263-270.

Kreutzer K., Beier C., Bredemeier M., Blanck K., Cummins T., Farrell E.P., Lammersdorf N, Rsamussen L., Rothe A., Visser P., Weis W., Weiß T., Xu Y.J., 1998: Atmospheric deposition and soil acidification in five coniferous forest ecosystems: A comparison of the control plots of the EXMAN sites. Forest Ecology and Management **101**, 125-142.

Marschall J., 1975: Hilfstafeln für die Forsteinrichtung. Österreichischer Agrarverlag, Wien.

Matzner E., 1988: Der Stoffumsatz zweier Waldökosysteme im Solling. Berichte des Forschungszentrums Waldökosysteme/Waldsterben Göttingen, Reihe A, 40.

Mayer B., Bollwerk S.M., 2000: Controls of oxygen isotope ratios of nitrate formed during nitrification in soils. IAEA – Report CSP—2, Vienna.

Mutsch F., 1998: Indication of long-range transport of heavy metals based on the Austrian Forest Soil Monitoring System. Environmental Science and Pollution Research, Special Issue **1**, 81-87.

Mutsch F., 2001: Bodenchemische Charakterisierung des Mühleggerköpfls im Rahmen einer Untersuchung über Stickstoff-Flüsse in den Nordtiroler Kalkalpen. FBVA-Berichte **119**, 33-40.

Nilsson S.I., Berggren D., Westling O., 1998: Retention of deposited NH_4-N and NO_3-N in coniferous forest ecosystems in Southern Sweden. Scand. J. For. Res **13**, 393-401.

Ortloff W., Schläpfer R., 1996: Stickstoff und Waldschäden: Eine Literaturübersicht. Allg. Forst- und Jagdztg. Jg. **167**, 9-10, 184-201.

Raspe S., 1988: Ausbildung und Mineralstoffgehalte des Wurzelsystems der Fichte (Picea abies Karst.) auf Buntsandstein- und Braunerde im Stadtwald Villingen. Diplomarbeit, Institut für Bodenkunde der Forstwiss. Universität Freiburg i. Br.

Schulze E.D. (ed.), 2000: Carbon and nitrogen cycling in European forest ecosystems. Ecological Studies 142, Springer.

Simunek J., Sejna M., van Genuchten M.T., 1998: The Hydrus 1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably saturated media. Research Report IGWMC-TPS 70. Colorado School of Mines, Riverside, CA, Golden, CO.

Smidt S., 1998: Risk assessment of air pollutants for forested areas in Austria, Bavaria and Switzerland. Environmental Science and Pollution Research, Special Issue **1**, 25-31.

Smidt S., Herman F., Grill D., Guttenberger H. (eds.), 1995: Studies of ecosystem in the Limestone Alps – "Achenkirch Altitude Profiles". Phyton (Horn, Austria) 34 (3).

Smidt S., Herman F., Grill D., Guttenberger H. (eds.), 1996: Studies of ecosystem in the Limestone Alps – "Achenkirch Altitude Profiles". Phyton (Horn, Austria) 36 (4).

Smidt S., Herman F., Englisch M. (eds.), 2002: Nitrogen fluxes in the Tyrolean Limestone Alps. Environmental Science and Pollution Research, Special Issue 2.

Smidt S. & Herman F., 2004: Evaluation of air pollution related risks for Austrian mountain forests. Environmental pollution 130, 99-112.

Stark J.M., Hart S.C., 1997: High rates of nitrification and nitrate turnover in undisturbed coniferous forests. Nature **385**, 61-64.

Stefan K., Fürst A., 1998: Indication of S and N inputs by means of needle analyses based on the Austrian Bioindicator Grid. Environmental Science and Pollution Research, Special Issue **1**, 63-69.

Tietema A., Boxman A.W., Bredemaier R., Emmett B.A., Moldan F., Gundersen P., Schleppi P., 1998: Nitrogen saturation experiments (NITREX) in coniferous forest ecosystems in Europe. A summary of results. Environmental Pollution **102 (1)**, 433-438.

Tietema A., (1998): Microbial carbon and nitrogen dynamics in coniferous forest floor material collected along a European nitrogen deposition gradient. Forest Ecology and Management **101**, 29-36.

Van der Hoek K.W., Erisman J.W., Smeulders S., Wisniewski J.R., Wisniewski J. (eds.), 1998: Nitrogen, the Confer-N-s. First Int. Nitrogen Conference 1998. Environmental Pollution **102** (1).

WHO, 2000: Air Quality Guidelines for Europe. Second Edition. World Health Organization, Regional Office for Europe. Copenhagen.

Wright R.F., Rasmussen L., 1998: Introducion to the NITREX and EXMAN Projects. Forest Ecology and Management **101** (1-3), 1-7.

Wright R.F., Tietema A., (eds.), 1995: NITREX. Forest Ecology and Management **71** (Special Issue).

FOREST HYDROLOGY AND CLIMATE CHANGE – CASE STUDY MÜHLEGGERKÖPFL

FORSTHYDROLOGIE UND KLIMAWANDEL – FALLSTUDIE MÜHLEGGERKÖPFL

Robert JANDL*, Richard KNOCHE¶, Klaus KATZENSTEINER§

*Federal Office and Research Centre for Forests BWF, A - 1131 Vienna, Austria

¶Forschungszentrum Karlsruhe GmbH, Institut für Meteorologie und Klimaforschung, D - 82467 Garmisch Partenkirchen

§Institute of Forest Ecology, Department of Forest- and Soil Sciences, University of Natural Resources and Applied Life Sciences (BOKU), A-1190 Vienna, Austria

ABSTRACT

Within an interdisciplinary project on potential effects of global climatic change on forest ecosystems in the Alps, we simulated the water budgets of a mountain forest in Northern Tyrol under current and future climate conditions. The posed questions were if global warming will lead to a significant alteration of water budgets and soil water status at the experimental site. The forest hydrology model BROOK90 and the soil hydrology model HYDRUS1D have been calibrated using a five years time series of micrometeorological and hydrological measurements at the site. The future climate (two times CO_2 compared to present) was derived from the MM5/MCCM mesoscale climate model nested within the global climate model ECHAM3 (T106). The climate data have been adjusted for the local situation by comparing model results for the present situation and current meteorological data. Under the anticipated future climate the precipitation rate and the temporal distribution of the rainfall will not change significantly. Due to increased air temperatures and length of the growing season period, the annual transpiration of the forest will increase by almost 30%. Due to high overall precipitation the water demand of the forest will be fulfilled, stress situations may not be expected. Soils will be drier during the summer, what may have implications on microbial turnover rates. Additional consequences of climate change such as the adaption of the forest stand, the soil microbial activity, and the changed probability of biological and physical damages of the plants were not investigated.

KEYWORDS: climate change, simulation, forest ecosystem

ZUSAMMENFASSUNG

Im Rahmen eines interdisziplinären Projektes über die potentiellen Effekte des globalen Klimawandels simulierten wir die Hydrologie eines Bergwaldstandortes in Nordtirol unter den aktuellen und künftigen Klimabedingungen. Die Fragestellung war, ob sich die globale Erwärmung auf den Bodenwasserhaushalt auswirkt. Das Waldhydrologiemodell BROOK90 und das Bodenwassermodel HYDRUS1D wurden mittels einer Zeitreihe von meteorologischen und hydrologischen Messdaten von fünf Jahren kalibriert. Das künftige Klima (Verdoppelung der CO2-Konzentration in der Atmosphäre) wurde aus dem mesoskaligen Modell MM5/MCCM,

Forstliche Schriftenreihe, Universität für Bodenkultur Wien, Bd. 18, 2004, 169-180
ÖGWEB (Österr Ges f Waldökosystemforschung und experimentelle Baumforschung) ISBN 3-900865-17-5

genestet innerhalb des globalen Modells ECHAM3 (T106) abgeleitet. Die modellierten Daten wurden auf die lokalen Gegebenheiten justiert. Unter den künftigen Klimabedingungen wird sich die Niederschlagsmenge und die zeitliche Verteilung des Niederschlages nur wenig verändern. Durch die Temperaturerhöhung und die Verlängerung der Vegetationsperiode wird die Transpiration um 30% erhöht. Durch den hohen jährlichen Niederschlag ist nicht mit Wasserstress zu rechnen. Die Böden werden in Zukunft im Sommer trockener sein. Dadurch verändern sich die Bedingungen für mikrobiologische Umsetzungen. Weitere mögliche Veränderungen im Ökosystem wie etwa die Adaptierung der Bestände, die Veränderung der Bodenmikrobiologie und mögliche Schadwirkungen auf Pflanzen wurden nicht untersucht.
SCHLAGWORTE: Klimaänderung, Simulation, Waldökosystem

INTRODUCTION

The site Mühleggerköpfl in Achenkirch/Tyrol has been the subject of process studies in order to elucidate the biogeochemical cycle of nitrogen and the potential of N saturation. The concern was that nitrogen from atmospheric deposition will leach from the shallow soils on calcareous bedrock into the river and will pollute the aquifer. This scenario is critical because forest ecosystems are generally considered as the parts of the landscape where the chemical quality of the water is rather high. Indications for N leaching show that the existing forest ecosystems cannot or can no longer serve this purpose. An elaborate field experiment solidly established, that presently hardly any N leaches into the groundwater. Instead, the major part of the incoming N is retained in the forest soil and N export is limited to rare occasions. Nevertheless, it was realized that the ecosystem is presently not in steady state. Like many Central European forests the Mühleggerköpfl benefits from N inputs and is currently aggrading. The nutrient pool recovers from the depletion as consequence of former land-use practices. The question was posed how long the forest will be able to scavange incoming N and if N saturation is likely in the foreseeable future. Predictions of the future biogeochemical cycles require assumptions about the climate. Expert opinion is equivocal that the climate in Central Europe will change markedly in the next decades and that the human induced increase in the partial pressure of CO_2 (pCO_2) in the atmosphere is a major driver of climate change (IPCC 2001). Doubling of the present pCO_2 in the next century is possible and it will be difficult to stabilize pCO_2 at this high level (Hoffert et al., 2002). An increase in the global temperature will be somewhere between 1.4 and 5.8°C. Climatologists agree that regional and seasonal differences will be large. For Europe an increase in flooding events, a higher frequency of intense rain and much warmer summers with abundant thunderstorms are predicted, but these forecasts are indeed controversial (Christensen and Christensen 2003, Mudelsee et al. 2003). For Northern Tyrol and Southern Bavaria the simulations predict drier and warmer summers. Winter precipitation is expected to remain unchanged and the increase in temperatures will vary locally. The increase of the average annual temperature will occur mostly during the summer months and will therefore be accentuated in the growing season. Spring, fall and the duration of the snow cover will be shorter. We ran simulations of the hydrology at the site under present and future climate conditions and compared the respective outcomes. We derived an estimation of the soil water status in 50 years from now by running a soil hydrological model with data derived from the regionalized climate simulation model MM5/MCCM under the IPCC scenario IS92a ('Business as Usual'); (Grell et al., 2000b, Knoche et al., 2003). The future climate was superimposed on the measured record of meteorological data of the experimental site Mühleggerköpfl.

SITES AND METHODS

The Mühleggerköpfl is located in the province of Tyrol. The site is located on a SE facing slope in 900 m a.s.l. Then mean annual precipitation is 1420 mm, the annual mean temperature is 6.5°C, and the snow cover lasts for 150 days (30 year averages, Station Achenkirch, Hydrologisches Jahrbuch der ZAMG). The bedrock is dolomitic limestone from which both rendzic Leptosols and chromic Cambisols have developed. Soil properties vary on a small scale within a wide range. The stand consists of mature Norway spruce and some beech and larch. A more detailled account of the site conditions is given in Herman et al. (2004).

Forest hydrology was simulated with the model Brook 90 (Federer, 1995; Katzensteiner, 2000) with the local meteorological record and site and stand descriptive parameters as input data. We then fed the soil hydrological model HYDRUS1D (Simunek et al., 1998) with the water demand of the forest, as derived from the simulations with Brook90, the measured meteorological data, and validated soil physical parameters (Jandl et al., 2002). The results were the pressure head of the soil water which is related to the soil water content and the annual seepage water flux.

The future climate was derived from a simulation model. The global climate model ECHAM3 (T106) has a spatial resolution of 120 km and cannot account for regionally important factors such as mountain ranges. The Alps are simplified to a valley-less solid pyramid of a maximum height of 2000 m that emerges near Munich, rises to the peak and declines again to reach sea level in the vicinity of Milano. In order to derive relevant climate simulations in the complex terrain of the Alps, the regional simulation model MM5/MCCM (5^{th} generation Mesoscale Model/Multiscale Climate Chemistry Model, Grell et al., 2000a) is nested within the global model ECHAM3. The spatial resolution is increased in two steps to 15 km (Grell et al., 2000b). However, the boundary conditions of the regional model are derived from the global model. Hence, any bias of it is transferred to local conditions. We had access to a 5 year time series of the present and the future climate, 50 years apart.

The results of the regional local scenario were not directly used, because they were biased. The simulated annual precipitation for the site Mühleggerköpfl both for the presence and the future ranged from 500 to 700 mm, which is roughly the half of the measured rainfall.

We assumed that, although the regional model yields biased data, the bias of the simulated data is systematic. A comparison of the present and the future climate is therefore valid, even when the simulated data carry a bias. The ratio of simulated precipitation rates of the modelled values for 'presence' and 'future' was used to calculate the future precipitation rate from measured data. We compared the simulations of the presence and the future (2 times CO2 according to IPCC IS92a) based on time series of 4 years. 'Presence' was represented by 1998-2001, 'Future' by 2046-2050. The datasets were split into months, because we needed to capture a temporally refined impact of climate change. The correction factors were absolute differences between the scenarios future and presence for minimum, average, and maximum air temperatures and ratios for the humidity, the solar radiation and precipitation. No correction for the wind velocity was performed.

We then fed the HYDRUS1D model with the scenario 'future' climatic conditions. The soil parameters of HYDRUS1D were left unchanged and the climate data were changed according to the model. We estimated the future transpiration of the forest, the soil water content and the annual seepage water flux.

RESULTS

Currently, the site Mühleggerköpfl has no particulary dry season. Short and heavy rainfall events are common. Under changed climate conditions the annual precipitation regime will only change slightly (Figure 1, Table 1). The intensity of single events may change though, because the warmer atmosphere will be more often instable in summer and will give more frequently opportunities for thunderstorms. In consequence, figure 2 shows a higher frequency of days with high infiltration rates under future climate conditions.

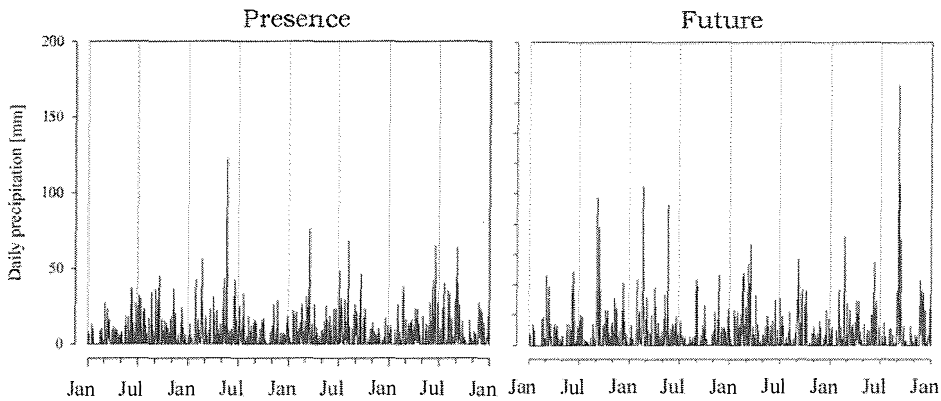


Fig. 1: Measured (left) and simulated (right) precipitation at the experimental site Mühleggerköpfl; 'Presence': 1998-2001, 'Future': 2046-2050.

Abb 1: Gemessener (links) und simulierter (rechts) Niederschlag am Versuchsstandort Mühleggerköpfl. 'Gegenwart': 1998-2001, 'Zukunft': 2046-2050.

The temperature is expected to rise considerably in the next decades. Figure 3 shows that the temperatures during the cold season will change only little. In the simulation exercise the growing season (T>5°C) was elongated by 9 to 14 days per year, the number of days with temperatures above zero was increased by 2 weeks. The summer temperatures will rise by a wide margin (Figures 3 and 4).

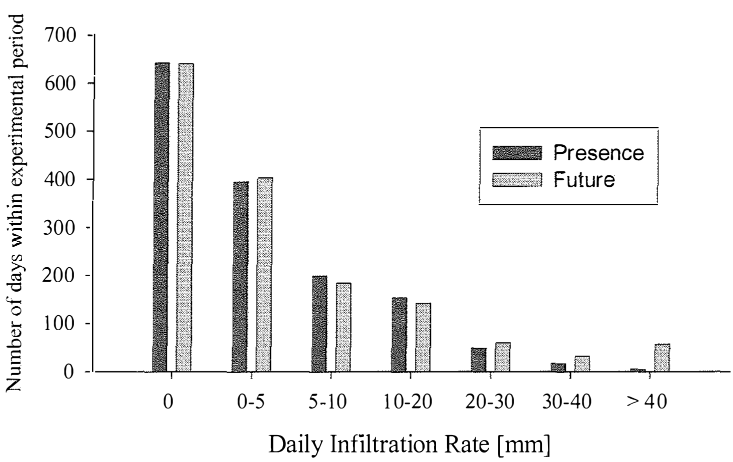


Fig. 2: Daily infiltration rate at Mühleggerköpfl.

Abb 2: Tägliche Infiltration am Mühleggerköpfl

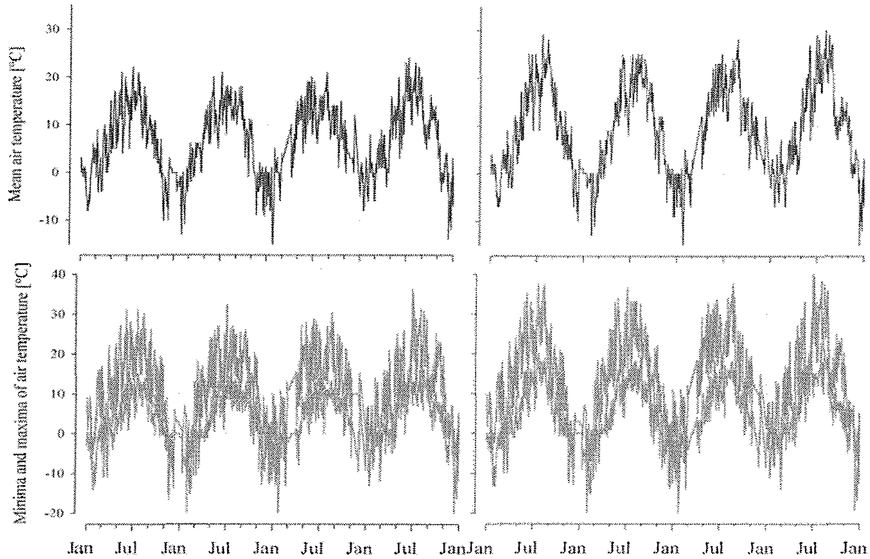


Fig. 3: Air temperatures at the experimenal site Mühleggerköpfl. Mean air temperatures (upper panel), range of maxima and minima temperature (lower panel). 'Presence': 1998-2001, 'Future': 2046-2050.

Abb. 4: Lufttemperatur am Standorte Mühleggerköpfl. Mitteltemperatur (oben), Maxima und Minima (unten).. 'Gegenwart': 1998-2001, 'Zukunft': 2046-2050.

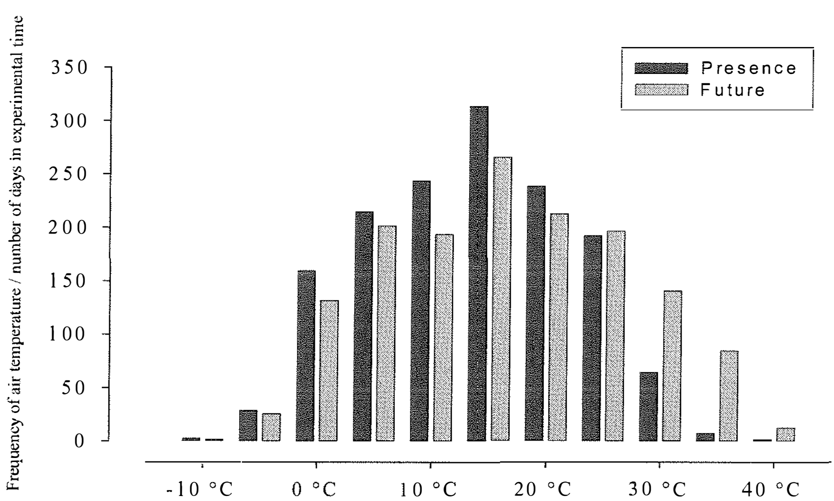


Fig. 5: Frequency of air temperatures at Mühleggerköpfl for 'Presence': 1998-2001 and 'Future': 2046-2050.

Abb. 6: Häufigkeit der Lufttemperaturen am Mühleggerköpfl. 'Gegenwart': 1998-2001, 'Zukunft': 2046-2050.

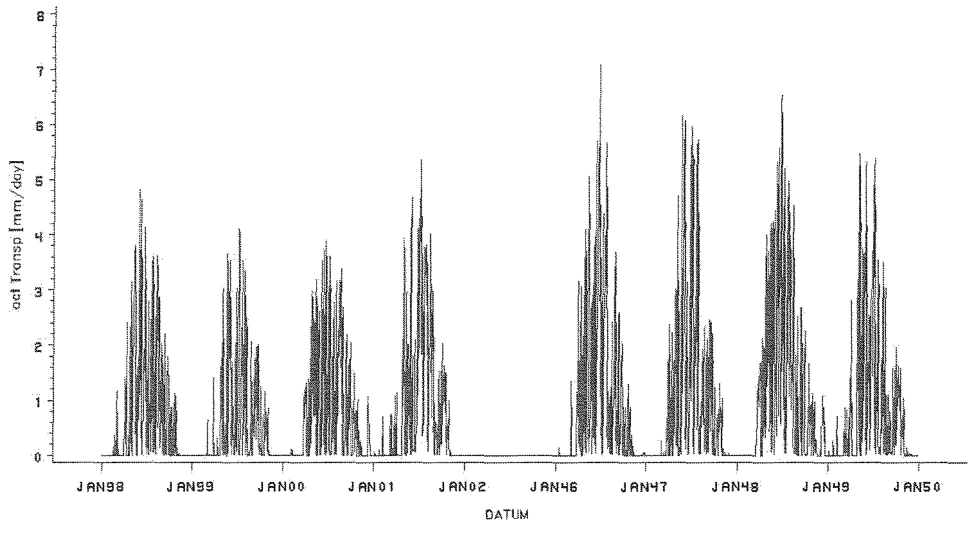


Fig. 7: Daily actual transpiration rate [mm/day] at the Mühleggerköpfl; 'Presence': 1998-2001, 'Future': 2046-2050.

Abb. 8: Tägliche aktuelle Transpirationsrate [mm/Tag] am Mühleggerköpfl; 'Gegenwart': 1998-2001, 'Zukunft': 2046-2050.

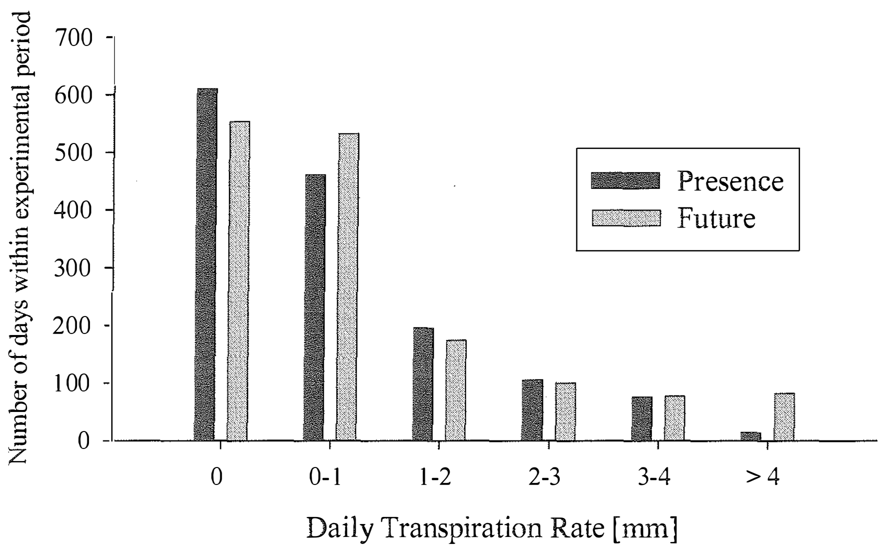


Fig. 9: Frequence of the daily transpiration rate at Mühleggerköpfl for the presence and the future.

Abb. 10: Häufigkeit der täglichen Transpirationsrate am Mühleggerköpfl in der Gegenwart und Zukunft.

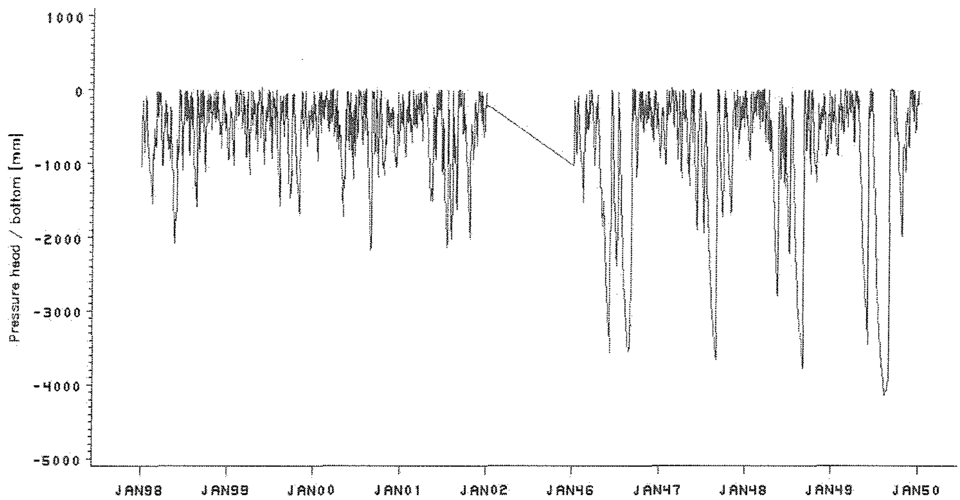


Fig. 11: Pressure head (cm) of the soil water at the lower end of the rooting zone.

Abb 7: Druckhöhe (cm) des Bodenwassers am unteren Ende des Wurzelraumes.

Temperature is an important driver for the transpiration rate of the forest. At a higher water pressure saturation deficit, more water is transported through the system (Figure 5, Tables 1 and 2). The prediction for the Mühleggerköpfl is an increase from approx. 250 to 350 mm annual transpiration. The response of the transpiration rate to climate change is strong, because the rich water supply in the area with luxuriant precipitation supply virtually allows unlimited water use for plants. Figure 7 suggests that the soil water content in the rooting zone will be lower in future summers. Nevertheless, soil water will not be a limiting factor. The trees will almost always be able to fulfill their water demand from the soil. In Figure 6 the distribution of the daily transpiration rate is shown. Days without transpiration are getting less frequent and the number of days with high transpiration rates will become more common.
The seepage rate of water is presently quite variable. It strongly depends on the frequency of episodes of heavy rainfall. In such times, water flows quickly through the porous soil. The water retention capacity of the soil is limited because the soil is shallow and has a high content of coarse fragments of dolomite. Due to high biological activity and root channels, macropores are abundant. No soil horizon has been identified as a strong barrier for the downward transport. Surface flow may only occur over short distances. At the high amount of incoming water the transpiration of plants is always a minor contributor to the annual water balance.

Tab. 1: Precipitation, transpiration, evaporation, and runoff (mean and standard deviation) at Mühleggerköpfl.

Tab. 1: Niederschlag, Transpiration, Evaporation und Abfluß (Mittel und Standardabweichung) am Mühleggerköpfl.

	Precipitation [mm]	Intercepted precipitation evaporation [mm]	Soil Evaporation [mm]	Transpir- ation [mm]	Evapo- transpir- ation [mm]
Water balance current (n= 4 years)	1874 +/- 126	497 +/- 24	24 +/-5	255 +/-47	776 +/- 86
Water balance future (n= 4 years)	2071 +/- 207	469 +/- 20	20 +/- 6	345 +/- 52	831 +/- 110

Tab. 2: Summary of key values for the forest hydrology at Mühleggerköpfl.

Tab. 2: Zusammenfassung der wichtigsten hydrologischen Kennwerte am Mühleggerköpfl.

Year	infiltration [mm/year]	transpiration [mm/year]	leaching [mm/year]
1998	1456	255	1201
1999	1706	183	1523
2000	1657	266	1391
2001	1686	294	1392
2046	1638	325	1313
2047	1847	316	1530
2048	1738	408	1330
2049	1805	246	1500

DISCUSSION

Climate change is real and the linkage to the anthropogenic emissions of greenhouse gases is well established. Manifold publications suggest a global increase of the temperature of several degrees with consequences such as melting of the ice caps of the Poles, shrinkage of glaciers, and an increase in desertification in already vulnerable areas (IPCC, 2001). These model-based predicitions are considered to be accurate with respect to the future temperatures. The forecast of the future precipitation is less certain (Formayer, 2003). Forest managers need to base their silvicultural decisions on assumptions of future site conditions. Now immature forest stands will cope with an environment that will differ from the present conditions to a large extent. Predicitions of the local climate that can be expected in several decades are rarely available, although climate change will have an impact on the hydrology of forested watersheds. Considering that climate change may be the severest environmental problem (King, 2004), the data base for educated guesses in a regional context is dramatically small.

The most striking result of the climate simulation is the large increase in temperatures during the growing season. Winter temperatures will likely change far less. The influence of arctic air, that causes very cold episodes of sometimes several week, will also be effective in the future. The temperature increase will occur between spring and fall. The snow cover during spring season will be shorter. Similar concerns have been expressed for many other areas (Fukushima et al., 2003).

With respect to the water demand of the spruce forest at the Mühleggerköpfl our hydrology simulations do not indicate any dramatic change. The annual precipitation rate will rise by about 10%. The water supply to the site is high and evenly distributed over the year that even in a much warmer climate the plants will have sufficient soil moisture to their disposal. The soil can sustain an almost 30% increase in the transpiration rate. The higher water demand of the trees will temporarily lead to a lower soil moisture content as currently measured, but soil water will be plant-available and a growth limitation due to water stress is unlikely.

The water leaching rate of the site will change only little. The increase in the annual transpiration is a rather small signal, compared to the large water fluxes of the precipitation and the outflux. In this project we have not speculated on the chemical composition of the soil solution in a warmer climate. It is, however, reasonable to assume that the microbial activity will accelerate and the rate of N mineralization will increase (Rustad et al., 2001). The results for the Mühleggerköpfl with respect to nitrogen dynamics are explained in a companion paper (Herman et al., 2004; this volume).

Short-comings of the modelling approach are (1) the short time period (4 years) that form the basis of the climate scenario, the (2) arbitrary selection of ECHAM3, although other global models could show different results, and (3) that structural and physiological adaptations of the forest to the new atmospheric conditions were not taken into account. The soil hydrological model was run with the same stand parameters as presently found. We are confident, however, that the chosen site Mühleggerköpfl indeed represents an average forest stand of the region. We believe that no single potentially limiting site factor has been overlooked, that can compromise the growth of spruce in a warmer climate. However, we have no leads on the consequence of severe weather conditions that are believed to become more frequent in a warmer climate. It will be seen if physical damages to the forests due to storms and heavy snow loads will affect Norway spruce. Moreover, the interaction with biological threats such as pest infestations and insects was not investigated.

A finding of a Swiss research project had indicated that in the current climate almost 30% of the forest is rather poorly adapted to its site conditions. Moderate to strong warming increases the percentage of poorly adapted forests by 5-30% (Kienast et al 1996). Although lack of adaption is not a recognized problem in the area of the investigations, there are other locations nearby, where forests may not be maintained in a warmer climate. Inneralpine pine stands in Southern Tyrol are already at extreme site conditions due to the lack of precipitation. A changed water balance due to higher transpiration rates may put these forests at risk.

ACKNOWLEDGEMENTS

The climate data are derived from a global simulation and have been made available to us by the Forschungszentrum Karlsruhe, Institut für Meteorologie und Klimaforschung, IMK-IFU, (http://imk-ifu.fzk.de) in Garmisch-Partenkirchen. The study was supported by the Austrian Ministry of Agriculture, Forestry, Environment and Water management, Project Number 56.810/34-VA2b/200.

REFERENCES

Christensen J.H. and Christensen O.B., 2003: Severe summertime flooding in Europe. Nature **421**, 205.

Federer, C.A., 1995: Brook 90 - A simulation model for evaporation, soil water, and streamflow, Version 3.1, Durham NH.

Formayer H., Matulla C. and Haas P., 2003: Regional Climate Change Scenarios for Austria during the first half of the 21 Century and their possible consequences for the water cycle. Presentation at Conference 'Water and Society', November 19-21, Vienna, Austria.

Fukushima T., Kureha M., Ozaki N., Fujimori Y., and Harasawa F., 2003: Influences of air temperature change on leisure industries: Case study on ski activities, Mitigation and Adaptation Strategies for Global Change **7**, 173–189.

Grell G.A., Emeis S., Stockwell W.R., Schoenemeyer T., Forkel R., Michalakes J., Knoche R. and Seidl W., 2000a: Application of a multiscale, coupled MM5/chemistry model to the complex terrain of the VOTALP valley campaign. Atmospheric Environment **34**, 1435-1453.

Grell G.A., Schade L., Knoche R., Pfeiffer A. and Egger J., 2000b. Nonhydrostatic climate simulations of precipitation over complex terrain. Journal of Geophysical Research **105**, 29595-29608.

Herman F., Smidt S., Jandl R., Englisch M., 2004: Nitrogen flux studies in the North Tyrolean Limestone Alps. This volume

Hoffert M.I., Caldeira K., Benford G., Criswell D.R., Green C., Herzog H., Jain A.K., Kheshgi H.S., Lackner K.S., Lewis J.S., Lightfoot H.D., Manheimer W., Mankins J.C., Mauel M.E., Perkins L.J., Schlesinger M.E., Volk T., and Wigley T.M.L.: 2002: Advanced technology paths to global climate stability: energy for a greenhouse planet. Science **298**, 981-987.

IPCC TAR 2001. Climate Change 2001. The Scientific Basis. Summary for Policymakers

Jandl R., Spögler H., Šimunek J., and Heng L.K., 2002: Simulation of soil hydrology and establishment of a nitrogen budget of a mountain forest, Environmental Science and Pollution Research Sp. Issue **2**, 42-45.

Katzensteiner K., 2000: Wasser- und Stoffhaushalt von Waldökosystemen in den nördlichen Kalkalpen, Forstliche Schriftenreihe der Universität für Bodenkultur **15**, 1-159.

Kienast F., Brzeziecki B. and Wildi O., 1996: Long-term adaptation potential of Central European mountain forests to climate change: a GIS-assisted sensitivity assessment Forest Ecology and Management **80**, 133-153.

King D.A., 2004: Climate change science: adapt, mitigate, or ignore? Science **303**, 176-177.

Knoche R., Forkel R. and Kunstmann H., 2003: Regionale Klimasimulationen für Süddeutschland und den Alpenraum. In: "Klima - Wasser - Flussgebietsmanagement - im Licht der Flut - Beiträge zum Tag der Hydrologie am 20./21. März in Freiburg i.Br.", pp. 11-18, (Hsg.): Hans-B Kleeberg. Hydrologische Wissenschaften - Fachgemeinschaft in der ATV-DVWK, D-53758 Hennef, 2003.

Mudelsee M., Börngen M., Tetzlaff G. and Grünewald U., 2003: No upward trends in the occurrence of extreme floods in central Europe. Nature **425**, 166–169.

Rustad L.E., Campbell J.L., Marion G.M., Norby R.J., Mitchell M.J., Hartley A.E., Cornelissen J.H.C. and Gurevitch J., 2001: A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming, Oecologia **126**, 543-562

Šimunek J., Šejna M. and van Genuchten M.Th., 1998: The Hydrus-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably saturated media, Research Report IGWMC-TPS 70, Golden, Colorado School of Mines, Riverside, CA.

Smidt S., Herman F., and Englisch M. (eds.), 2002: Nitrogen fluxes in the Tyrolean Limestone Alps. Environmental Science and Pollution Research, Special Issue 2.