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Human Impact on the Physico-geographical Processes

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# PREFACE

The present volume contains nine reports read at the Second Polish-Hungarian Seminar, which was organized by the Geographical Research Institute of the Hungarian Academy of Sciences and held at Budapest on September 11–15, 1975.

Participants were nine Hungarian geographers and seven Polish geographers. The topic discussed was: "The Effect of Man's Activities upon Physico-geographical Processes". Altogether fourteen papers were read; they commented on the methods applied by the authors, and upon their effect on various physico-geographical processes resulting from different human activities (agriculture, forestry, hydrography, industry and mining). Much attention was also paid to forecasting what evolution of the geographical environment was to be expected from man's endeavours.

This Seminar reflects the co-operation initiated in 1973 by the Symposium held in September 1973 at Szymbark near Gorlice. The material dealt with at this meeting has been published in *Földrajzi Értesitö,* vol. 23, No. 2, 1974.

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# LANDSLIDES AT DUNAFÖLDVAR IN 1970 AND 1974

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## 1. PRECONDITIONS FOR THE LANDSLIDE

(a) The Dunafoldvar landslide belongs to the type of imbricated slice-slides (M. Pecsi, 1972, 1975). It was formed under *particular morpholithogenetic conditions*. The thick loess cover of the Mezofold ends on the right bank of the Danube in steep, high bluffs. The various loess sandy and loamy layers of the some 50 m thick loess sequence are in a nearly horizontal position on the impervious Pannonian clay substratum (Figure 1). The clayey strata are situated at the level of the Danube. The Pannonian clay provides favourable conditions for the formation of a sliding plane: its inclination is only slight or horizontal though its surface is somewhat uneven.

(b) The *hydrogeological condition* favourable for imbricated slice-slides is provided by the percolation of water at the contact of the permeable clay layers and the loess sequence. Wherever and whenever the waters seeping through these layers are not tapped by springs at the foot of the bluff, the lower layers in the loess sequence are highly saturated. At the site of the Dunafoldvar landslide this process was supported by a slight trench-like depression, i.e. a buried flat valley coming from NW to the Danube situated on the impermeable clays. In the contact zone, enormous amounts of water seeping through and accumulating below the surface are a common phenomenon after wet seasons or wet years.

The summer was very wet in 1970 and the amount of precipitation during the year prior to the date of the landslide was more than 600 mm. The annual average precipitation in Dunafoldvar and its closest environs is about 500 and 550 mm. The Oreg-hegy in Dunafoldvar is a relatively small isolated loess butte where rainwater will run off mostly along the deep loess roads. It was at the site of this butte that the landslide took place for a length of some 700 m south of the 1560 km river post. An above-average precipitation is not enough to saturate the 40-50 m thick loess sequence, let alone to provide enough water for the springs. The springs are fed by groundwater at the foot of the bluff on the shore of the Danube. The water supply of groundwater probably comes from the valley west of the loess butte running along the "background" Mezofold. The bottom of this valley is 100 m a.s.l. at Dunafoldvar and it decreases to 98 m to the south. On the basis of the examination of the cross-section we may presume that this level is between that of the red clay and the dark-grey loamy soil overlying the Pannonian clay. It is very much the same as the vertical position of the slightly pink-coloured sandy, loess-like layers in the lowest 4 to 5 m of the Dunafoldvar bluff. Possibly percolation of water takes place at the
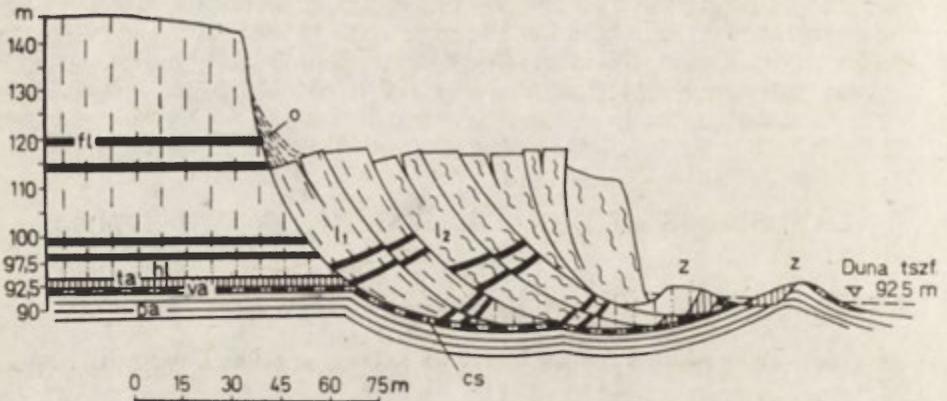
Fig. 1. The Dunaföldvár river-bank landslide to the South of the Danube's kilometre
mark

1 — loess sequence in primary position (autochthonus); $l_1$ — loess recently displaced by sliding;
$l_2$ — waste of earlier slides; hl — pale pink sandy loess; o — talus; z — earth mound and
Pannonian clay upward from the Danube's stream bed; fl — fossil soils; ta — dark-grey clayey
loam soil; pa — Pannonian clay; va — red clay; cs — sliding plane

bottom of the layers along earlier small buried valleys. This means that the
sequence of the loess layers will not be soaked from above but water will rise
from the base upwards, depending on the nature of the rock, the intensity of
percolation and the pressure exerted by the overlying layers.

(c) *Earlier and recent landslides.* Prior to the landslide of 15 Sept. 1970 there
were several movements in the same place in the Dunaföldvár bluff (Figure 1).
As a result of the earlier landslides the loess bluff 150 m a.s.l. has retreated
in a section of some 50 to 70 m in width. The bulk that slid down earlier re-
sulted in the formation of a bench 115 to 120 m a.s.l. On the bank of the Dan-
ube (92.5 m a.s.l.) this also ends in a bluff. This bench has virtually become sta-
bilized; houses have been constructed on it since.

Months prior to the 1970 landslide fissures became visible on the loess pla-
teau, parallel to the steep rim. The network of these fissures was reported by
local people to have become gradually wider and deeper. These people were
conscious of slight movements in the days prior to the landslide. The landslide
in question resulted in the movement of a slice of loess with an average width
of 30 m and a length of some 700 m removing a semi-circular slice from the
bluff. The thickness of this slice may have been some 45 to 50 m. The bulk
in question was some one million m³ and it crashed down vertically some 30 m
as compared to its original position. At the time of the landslide a great noise
was heard and dust-clouds were produced. In the bed of the Danube, near to
the shore and in front of the sliding surface two arcs of islands nearly parallel
with each other were produced and pushed up 2 to 5 m above the water level
(Figure 2). People who were present at the time of the landslide saw waves more
than 1 m high being produced and hitting against the opposite bank with
great force. The surface of the slice became covered by talus on the side of the
bluff, while towards the Danube a trench 3 to 5 m wide was formed and, be-
tween these, parallel ridges 2 to 4 m high were formed. The bench to the left of
the earlier landslide became dissected by broad fissures, and ridges 2 to 4 m
wide either rose up or subsided. On the edge of this bench near to the Danube
vertical movement was slightest. The horizontal movement of the sliding bulk
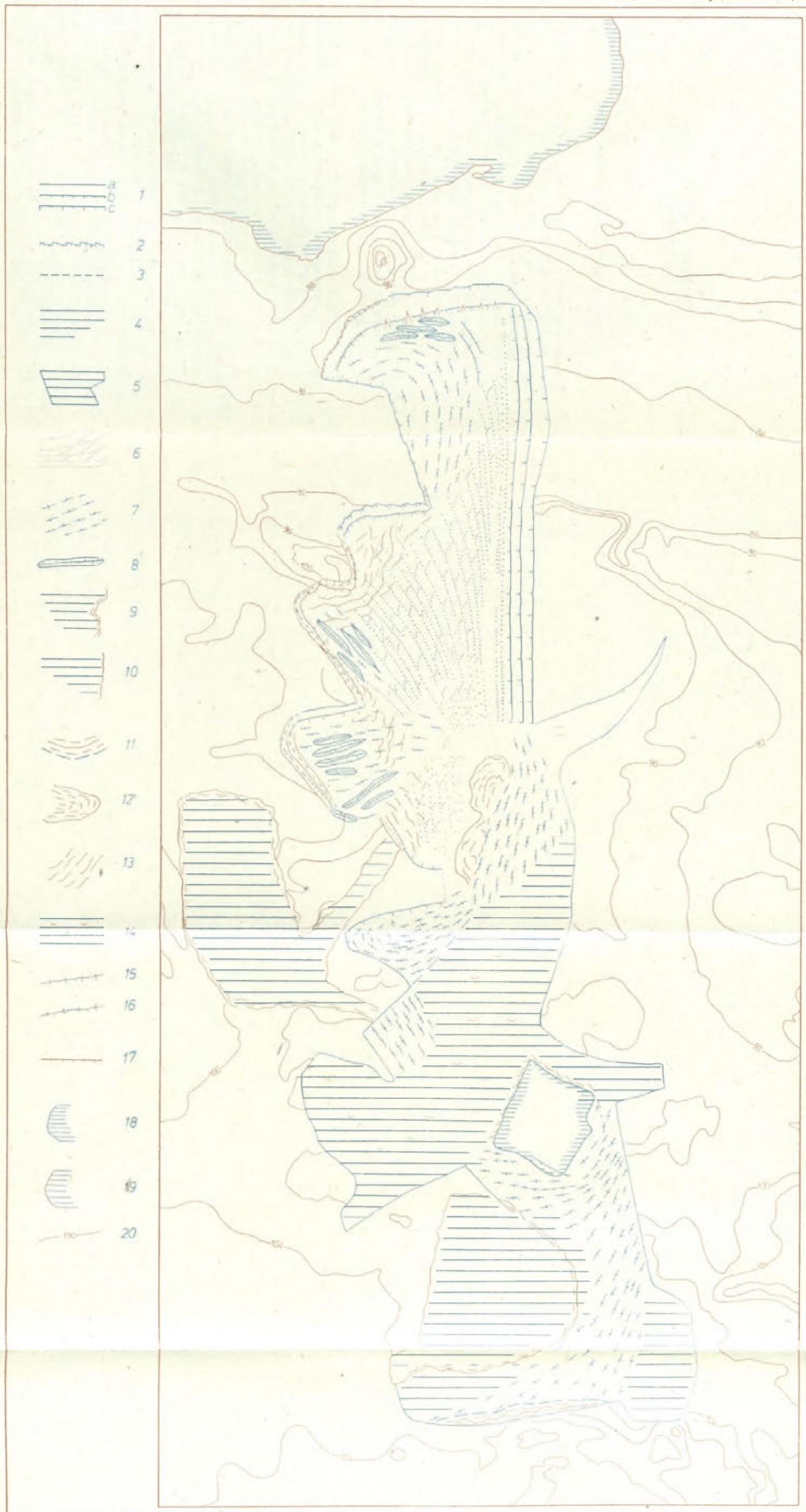
Fig. 3. A map of changed relief of post-mining areas — phase III (on the basis of aerial photographs and field observations)
1 — Slope formed by dissection of surface during removal of overburden: a — up to 2 m high, b — 2-5 m high, c — more than 5 m high, 2 — Slopes of undulating-indented outline, 3 — A former course of the slope poorly visible, 4 — Surface of outer dump, 5 — Surface of inner dump, 6 — Traces of removal of coal or overburden, 7 — Surface of unlevelled dumping of ground masses, 8 — Longitudinal dumping ramparts, 9 — Slopes of outer dump formed by large-scale processes (downfalls, slumpings, creepings, etc.), 10 — Downfalls and slumpings in slope area of unchanged surfaces, 11 — Slope of outer dump slightly changed by wash-downs, 12 — Large slumping tongues in area of outer dumping, 13 — Area of massive movements on inclined surfaces with small discontinuous slopes (large alluvial cones), 14 — Oval downwarping of surface of inner dump — suffusional type, 15 — Small dissections of slopes, 16 — Large dissections of slopes having wide cones at the foot, 17 — Natural slopes formed during slumping and down-falls: a — up to 2 m high, b — 2-5 m high, c — more than 5 m high, 18 — Artificial water basins, 19 — Natural water basins, 20 — Contour lines

towards the Danube was greater in the northern section of the landslide, while it seemed less important to the south. This is due to the curve of the landslide reaching the present-day bank of the Danube only in the north. At this point, however, in the foreground of the landslide, the bench formed by the former landslide could counter-balance this weight. The waste of earlier slides became remobilized on the side of the new slide, was dissected by fissures, and in some places smaller slices subsided or protruded. The position of the fissures and elevated land slices suggest that the slices produced by the new landslide slid under the old mobilized mass.

## 2. THE PROCESS OF AN IMBRICATED SLICE SLIDE

In the Dunafoldvar bluff the vertical fissures parallel to the bank became visible when the lower layers in the dry loess sequence lying on top of the red clay bed became saturated to such an extent that the cohesion strength of the grains was weakened. At first the collapse was of a small size* but enough to produce deep ruptures along a network of fissures of about 76 to 85 degrees in slices parallel to the bluff. The disjunction of slices, however, were not yet complete at that time because the disrupted slices were still supported by the bluff, and still remained *in situ*. This state could have persisted several weeks or even months until the lower loess layer became more and more moistened and the stability of cohesion was abruptly upset as a result of pressure effected by the soil slices. This phenomenon took place at a time when there was a critical value balance of moisture and pressure. At the time when sudden overbalance occurred in the basal loess layer the overburden dropped with force into the moistened flexible clayey base underneath. In the case of the imbricated slide at Dunafoldvar the potential sliding-plane was pre-formed in the contact zone of the nearly horizontal substratum of Pannonian clay and the loess sequence overlying it. The huge bulk of the loess slices exerted great pressure and slid along the flat depressed curve along the preformed sliding plane. In the foreground of the bulk that slid down, the plastic Pannonian clays protruded, exhibiting an upwarped and imbricated structure. The landslide at Dunafoldvar on this occasion resulted in the formation of two island arches that emerged from the river bed.

The low ridges off the headland appear like islands and consist of Pannonian clay and red clay overlying it; those nearer to the bank emerged from the material of the two lowest layers of the bluff, which slid into the Danube as a result of earlier landslides.

The imbricated slide at Dunafoldvar is a peculiar type of landslide which differs from other slump-slide types (M. Pecsi, 1968, 1971, 1972).

The imbricated slice-slide is characterized by the following:

(a) the potential sliding-plane is preformed due to the geomorphological and geological conditions;

(b) the imbricated slide and the sliding-plane will be formed in most cases at the edge of loess bluffs on impermeable clays lying in a horizontal position at the base level of erosion. The slide slightly undercuts the steep bluff;

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* The speed with which a collapse occurs in the loess (V$i$) is closely connected with the coefficient of filtration ($K = $ cm/s) and with the time necessary for saturation (t/s) when the thickness of the loess is $H$. The saturated layer of loess is affected also by the nature of the loess sequences, and their weight ($p$/kg/cm$^2$).

Photo 1. Inner "island" which was formed as a result of the slide-induced upwarping
of Pannonian clays of the stream bed overlain by red clays


(c) the moistening effect of the pervious layer conducting the filtrating wa-
ters percolating above the Pannonian clay; or of the intercalated uppermost
Pannonian sandy layers; or in places where the first artesitan watertable was
undercut by the river channel and was later buried by slope sediments;

(d) the moistened lower layers of the loess complex will loose their stability
of pressure and at a critical state of pressure and moisture shearing will take
place;

(e) the thick slices of loess that crashed down will move with a rotating, sli-
ding motion on the preformed sliding-plane and the horizontal displacement of
the mass is only slight.

On the other hand, in the case of slump-like landslides the sliding plane will
be formed within the mass of the clay where shearing would take place and
the semi-cylindrical surface of rupture will become the new sliding-plane. This
means that the potential sliding-plane is neither tectonically nor geologically
preformed. Moreover, there are important differences between these two types
of mass movement (imbricated slide and slump) in their hydrogeological and
hydrometeorological preconditions. Surface saturation is an important factor
in the case of slumps, while in the case of imbricated slides seismic movements
are very important besides various other preconditions.

On the basis of observations those parts of the bluffs along the Danube are
prone to landsliding where above the Pannonian clay a heavy filtration of
ground water takes place or springs are active. Such sections of the bluff will be
found along transverse fractures and also in cross-sections of former valleys
buried by loess. Periodical landslides will take place when several favourable

factors operate simultaneously, or occur at the same time. These include: years of heavy rainfall, important changes in the Danube water level, light seismic movements and artificial damming up of the water.



Photo 2. The Dunaföldvár river-bank landslide and its surroundings

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# THE ROLE OF EXTREME METEOROLOGICAL EVENTS IN THE SHAPING OF MOUNTAIN RELIEF

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## INTRODUCTION

The role of extreme meteorological events in the evolution of both slopes and valley floors is widely discussed in geomorphic literature. Whenever the activities of man disturb the dynamic equilibrium climate-soil-vegetation (Tricart and Cailleux, 1973) one may talk about catastrophic events. These limit production and they are often a danger to human life. However, the results of extreme events are not always dangerous as they do not hinder human activity. The extreme events I regard as short-term events which occur less than once a year (mostly once every few hundred years or every few tens of years). They disturb the dynamic equilibrium of both slopes and valley floors either created in climax conditions of a given morphoclimatic region or inherited from an earlier period. Those events are most intense and most frequent in environments with a disturbed equilibrium (Starkel, 1976).

In the present paper I concentrate on the extreme meteorological events (excluding the strong winds). These include:

(a) rapid downpours of high intensity, mainly local in range and connected with convection currents of the passage of cyclones;

(b) long-lasting continuous rains of lesser intensity and regional extent due to advection of oceanic air-masses;

(c) years and/or seasons with both precipitation amounts exceeding the mean values and low temperatures permitting the saturation of ground;

(d) periods of rapid warming (thaws) causing the quick melting of snow and ice as well as ground-thaw, often associated with precipitation.

The extreme events can be considered either in terms of meteorological cause or from the viewpoint of their geomorphological effects.

Meteorological phenomena may be compared by analysis of their intensity (amount of daily rainfall, mean and maximal intensity expressed in millimetres per hour and per minute) and frequency (not occurring each year, recurring in each century or even during the Holocene).

The morphological results of extreme events can be analysed both quantitatively (volume of mass displaced, index of slope lowering) and as relief-forming effects, i.e. the creation of new forms.

There is a diversity of viewpoints on the role of extreme events in the shaping of relief. Wolman and Miller (1960) analysing the activity of streams, stress events of medium·intensity rather than those of extreme character both in transportation (with as much as 90⁰/₀ of suspended load carried by rivers

during floods with recurrence periods of less than 5 years) and in the shaping of landforms (assuming the bankfull stage as critical). Mieshtcheriakov (1970) ascribes only a local role to them. However, Tricart (1963), Mortensen (1963), Rapp (1963, 1974), several Soviet geomorphologists (e.g., Rayonirovaniye SSSR, 1965) and the present author stress their importance in the fashioning of relief, although their effects may vary in particular zones of climate. Unfortunately, it is difficult to evaluate exactly the extreme events because of a lack of a dense network of research stations. Different phenomena are misinterpreted: The indices of slope denudation (often being much higher) are mainly based on measurements of suspended load in large rivers. The magnitude of relief change (creation of new forms) is deduced from multiyear measurements of slope wash and creep only.

THE MECHANISM OF CHANGES DURING THE EXTREME EVENTS

The occurrence of extreme geomorphological phenomena is controlled by the critical, limiting values of water circulation which depends on the volume, duration and intensity of precipitation, and on the ground features (Fig. 1). In analysing the slope water circulation model, it is possible to distinguish a few boundary surfaces at which changes in infiltration may allow new or extremely intense processes to occur. The first boundary surface is that of the topsoil. When the infiltration capacity of this soil is surpassed during intense rains, surface runoff begins and slope-wash and linear erosion result. The second boundary surface is the base of the *A* horizon (or of the arable layer), a surface separating two layers of different water holding capacity. Rapid flows of topsoil may then result. The third boundary surface is that between the regolith (waste mantle) and the bedrock. Water fails to soak into the bedrock and piping channels, mudflows, debris-flows, landslides and slumps result. The fourth boundary surface is formed by the irregular base of jointed rock. The presence of an overburden may lead to landslides and rock-falls.

The fashioning of both stream channels and flood-plains during the extreme events is controlled chiefly by the magnitude and violence of increase in discharges, by the load of sediment carried by the rivers and by the kind of
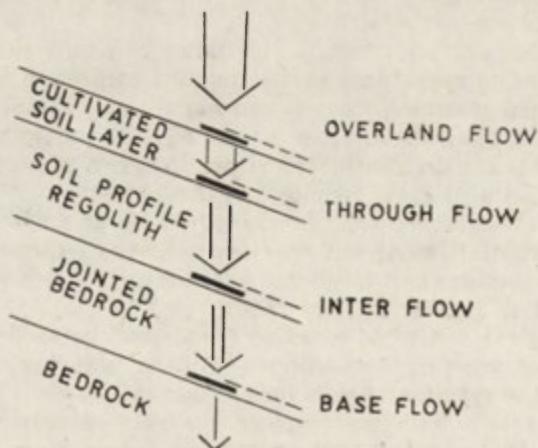


Fig. 1. The effect of varying permeabilities in different near-surface layers and of infiltration depth in the formation of surface and sub-surface run-off.

river-transported material as well. For this reason, extreme events may cause (i) channel deepening by the unloaded rivers (in resistant bedrock), (ii) the filling in of the stream channels and the building up of the flood-plains by slope material (braided rivers), (iii) increased erosion and deposition associated with the widening and lateral shifting of channels. The channel form becomes then adjusted to the magnitude of both discharge and transportation rate. Afterwards the river channel tends to restore a state of balance (Schumm, 1968).

There is a close relationship between the type of rainfall and the occurrence of extreme events. The higher the intensity of rains and the shorter their duration the smaller is the infiltration (Fig. 2). Thus, heavy downpours give rise to slope-wash and debris flows. In wet years with long-lasting rainfalls deep landslides occur. In the valley floors downpours of local range lead to local changes (except the *sjele*). Essential changes are the result of continuous rains during which stream levels rise in all drainage basins. On the other hand, channel forms are not altered in wet years with higher water levels, although the total amounts of river-transported material may be great.
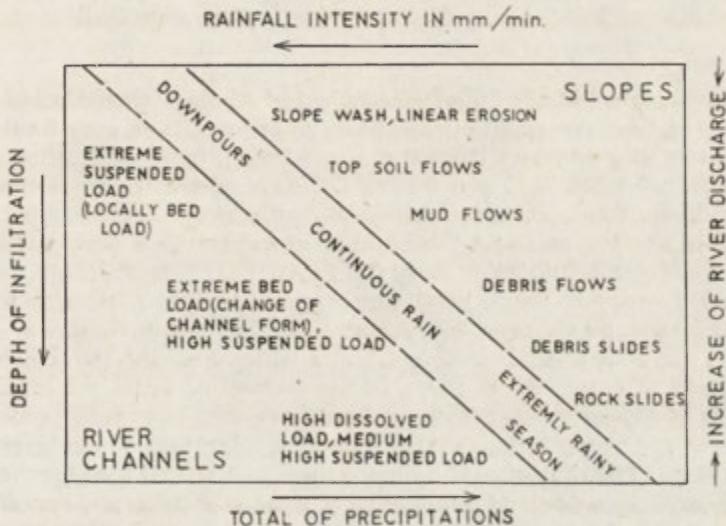


Fig. 2. Model of relationships between rainfall parameters, permeability of weathered rock horizons, depth of infiltration and type of slope and fluvial processes during extreme events.

THE INDIVIDUALITY OF MOUNTAIN AREAS

The highest extreme values of precipitation and the greatest morphological changes are observed in mountain areas. Mountains are typified by steep slopes and irregular river-beds of high inclination (Krivolutskiy, 1971; Hewitt, 1972). The vertical zonation of climatic belts each characterized by its distinctive suite of physical-geographic processes is responsible for the differences in both water circulation and importance of the particular extreme events in the vertical mountain profile (as altitude increases rapid thaws become more important). Mountains often show a temperature- and humidity asymmetry (exposure to rain-bearing winds). It is the marginal zone in a compact mountain massif that receives the heaviest precipitation rather than areas situated in the in-

terior of mountains (Weischet, 1969). At the same time, marginal zones are the most active tectonically and so most rapidly uplifted and dissected (Starkel, 1972a).

The precipitation inversion, together with the extent of cultivated areas defines the range of the occurrence of both extreme meteorological events and "catastrophic" geomorphological changes that are most frequently recorded in such areas. However, the extreme meteorological phenomena in a given mountain group preserve certain zonal features which are determined by the type of air circulation as welle as sets of climate-soil-vegetation systems developed in vertical form.

## THE ROLE OF EXTREME PHENOMENA, BEFORE AND AFTER DEFORESTATION IN VARIOUS CLIMATIC ZONES

Extreme events may act in a different fashion in the various climatic zones. This problem will be considered by taking as example the humid tropical, arid (steppe and desert) and temperate zones. These are characterized by the different shares of continuous rains, downpours and rapid snowmelts.

### (a) THE HUMID TROPICAL CLIMATE

In mountain areas of the equatorial zone and in areas with a monsoonal circulation the highest precipitation has been recorded. These may be downpours with a considerable intensity (50–300 mm per hour); more often they consist of continuous rains of 500–2000 mm lasting 2–3 days and with intensities of up to 50 mm per hour. While such rainfalls occur only every few ten years, annual daily maxima are 100 mm and the number of days with a precipitation above 50 mm ranges from 1–5 to 20 or more (de Ploy, 1972; Temple, Rapp, 1972; Starkel, 1972 a,b; Lundgren, Rapp, 1974). The effect of such rainfalls are, for instance, in Tanzania slope changes equivalent to a mean denudation rate of 14 mm. These were due to a rainfall lasting 3 hours which brought about debris flows and mud flows (Temple, Rapp, 1972). In the Darjeeling Hills, the effect of continuous falls of 700–1000 mm causing debris flows is equivalent to a mean denudation rate of 200 mm (Starkel, 1972a). The above data refer to deforested areas with steep slopes and they exceed by more than 50–100-fold the observed magnitude of changes in woodland with a very intense subsurface runoff. At one bankfull stage on the mountain streams, the 5-fold lateral enlargement of the channels (by undercutting of slopes and removal of terrace deposits) or considerable channel deepening can take place. Stream beds can also be raised by as much as 10 m in some stretches (local obstacles).

In the humid tropics, extreme phenomena occurring 5–10 times every century markedly surpass the mean 100-year denudation rate and control the creation of new forms. They also accelerate relief rejuvenation in the uplifted areas.

### (b) THE ARID CLIMATE (DESERT AND STEPPE ZONE)

Mountains of the arid zone are intensely fashioned during the heavy downpours and rapid melting of snow and ice. The latter event is common in the high mountains of Central Asia where it produces *sjels*. A single *sjel* can derive as much as 180,000 $m^3$ of material from 1 $km^2$ (Dumitrashko and o-workers, 1970). On the less inclined surfaces, slope-wash and piping play an essential role. They are most effective in areas where the poor vegetation has been destroyed by overgrazing. Such processes are best illustrated by the formation of ravines up to 15 m deep during a 488 mm rainfall lasting less than 12 hours which has been

observed by the present author in the Rajasthan (Starkel, 1972b). Extreme events are usually so rare that ravines are buried by moving sands. In the White Mountains, California, both erosional form and debris accumulations on the valley floors are clearly discernible after a few hundred years (la Marche, 1968).

In the arid regions extreme events are usually rare but they control the morphological evolution. In this zone, the "normal" processes include the effects of rapid downpours.

(c) THE TEMPERATE CLIMATE

In mountains, such as the Alps, the Carpathians and the Caucasus with 50-2000 mm annual precipitation, there occur both frontal and convectional downpours and continuous rainfalls due to the passage of cyclones, as well as rapid thaws. Continuous falls of 200-500 mm with an intensity usually below 10 mm per hour occur every few years. Downpours exceeding 100 mm (with maximal intensities 3-10 mm per minute) have been recorded locally.

Under natural conditions the equilibrium may be disturbed by exceptional meteorological events such as the downpour of 762 mm in 270 minutes in the Pennsylvanian Appalachians (Hack, Goodlett, 1960).

Detailed continuous measurements (e.g., at Szymbark in the Polish flysch Carpathians) and assessment of the effects of downpours revealed that slope changes caused by slope-wash (denudation rates of a few millimetres, Maruszczak, Trembaczowski 1959; Słupik, Gil 1972) were greatest on the beet- and potato fields. Materials derived from the slopes of less than 20° are laid down on the broad valley floors. During the continuous rainfalls subsurface runoff is predominant and mud flows and debris flows arise then (Starkel, 1960). However, in wet years with periodic continuous rainfalls and low evapotranspiration rates deep landslides occur, for instance, in 1913 (Sawicki, 1917) and in 1974 in the flysch Carpathians.

High stream discharges and channel widening due to both continuous rainfalls and rapid snowmelts have been reported from the Roumanian Carpathians (in 1970) and from the French Alps (Tricart, 1962). Deforestation of the mountain areas increases discharges and transportation rates. As a result, braided channels are developing in the valleys. However, in the present century gravel extraction, dam construction and channel corrections are the cause of stream channel deepening, even in the accumulational stretches extending along the margin of mountains (Klimek, Starkel, 1974).

THE ROLE OF EXTREME EVENTS IN THE EVOLUTION OF RELIEF

In mountain areas, extreme events lead to modification of the relief which becomes adjusted to the changing climatic and tectonic conditions. Under natural conditions in the belts of mountain forests and meadows, changes in the initial slope form (inherited from the Pleistocene and bearing debris, solifluctional and deluvial deposits) are due to the simultaneity of waste-mantle production, of a negative denudation balance and of slope dissection by gullies and chutes. The reduced supply of slope material into the rivers is favourable for the deepening of channels (Fig. 3).

Deforestation, farming and overgrazing caused changes of process type. The intensity of processes has increased 100-1000 times. New processes — unrecorded before — did appear (topsoil flows, deflation etc.). Both annual and extreme downpours of local range tend to be more important than the continuous rainfalls. As a consequence, some areas increase in valley density, and

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the deluvial valley fills vary in thickness there. The role of continuous rain-
falls is rather that of changing the channel forms, although falls are more dan-
gerous on the steep slopes (debris flows).

The extreme processes either accelerate or retard the natural trend of
relief evolution. The undermining of slopes during the floods brings about the
rejuvenation of uplifted areas. This is the positive feedback effect (Fig. 3). The
same phenomenon retards the maturation of slopes in the old mountains and
uplands. Because of subsurface runoff in the Holocene, the dissection of slopes
inherited from the periglacial morphogenesis is also a new, positive element.
The deforestation of such slopes can increase either dissection (accelerated re-
juvenation) or slope-wash. This leads to further maturation of the inherited,
concave-convex slope forms. The development of the newly-created forms (pro-
duced by strong impulses) can be continued during extremely intense pheno-
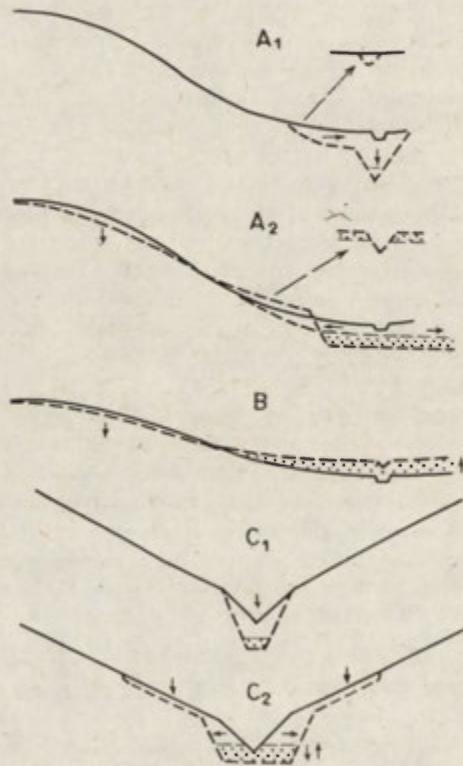


Fig. 3. Developmental trends in mountain slopes and valley floors during extremely
heavy rain

A. Upper portions of the Carpathian valleys:
    $A_1$ — deepening of valley floors and slope rejuvenation proceeding upslope (under natural
        conditions);
    $A_2$ — lateral erosion and aggradation of valley floors, slope dissection and building up by
        deluvia (after deforestation);
B — the Carpathian Foothills (after deforestation) — aggradation of valley floors and at slope
  foot due to deposition of deluvia;
C — the Darjeeling Hills (in the Himalayas) — zone of uplift
    $C_1$ — stream channel deepening (in forest)
    $C_2$ — stream channel deepening, lateral erosion and sedimentation, slope degradation (in
        deforested areas)

mena of greater frequency. It is only when the "normal" processes are also intense that such forms can be degraded and slowly fossilized (trough-like valleys in some cultivated areas).

In the vegetation-free areas with high frequency downpours, rock surfaces are swept bare and the dynamic equilibrium ceases to exist. Rocky deserts are formed as in the Upland of Assam (Starkel, 1972b) and in the mountains of the mediterranean zone. A new equilibrium quite different from the "normal" one is created.

On the contrary, slopes mantled with permeable debris are stable under climatic conditions of the Holocene. No essential slope changes take place now. Such slopes have been described by Rapp (1963). On this basis he concludes that the efficiency of the Holocene morphogenesis is rather low. This refers, however, to small areas which cannot be used for different purposes because of skeletal soils and steep gradients. When rainfall of a magnitude unrecorded during the prevailing environmental "equilibrium" does occur in such an area, chute and gully scars persist in the landscape inherited from an earlier morphogenesis (flows at Ulvadal).

The trend of mountain-valley evolution also depends on the fact whether or not the modification of both slopes and stream channels takes place at the same time, i.e. during the same meteorological events. According to Tricart (1962), in the Alps the fashioning of slopes and of valley floors is independent. However, data collected by the present author in India and by Rapp in Tanzania show that these are simultaneous processes. Variety is due to differences in the amount of precipitation in a given zone and in the maturity of mountain relief. In the Himalayas typified by steep slopes continuous rainfalls lead to both disturbance of slope equilibrium and river floods which can be increased by the local ponding of streams by landslides. In the broad Alpine valleys the slope material does not always reach the stream channels. In the Carpathians of low-mountain relief slope-wash is most intense during the downpours; deep landslides occur in the wet years, whereas floods on the larger rivers are the result of continuous rainfalls lasting a few days during which surface runoff is accompanied by the increased subsurface runoff.

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# SOME PROBLEMS OF SLOPE DEVELOPMENT REFLECTED IN SLOPE-PROFILE INVESTIGATIONS

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The basic problem of slope development concerning morphology and morphography is the following: what kind of forms develop on the slopes under certain conditions and as a result of a given dominant force, or forces, furthermore what the course is, and a prognosis of slope development? Yet slopes are not only the subject of geomorphological research, but also included in the study of soil erosion, water movement, etc. Part of the varied forms of human activity also takes place on slopes. In a broader sense, the greater part of areas classified as plains may be regarded as aggregates of slopes. Thus the investigation of the problems of slope development is important not only from the theoretical point of view, but its practical importance is likewise enormous.

It follows from the foregoing that experts in technical and agricultural sciences also deal with the problems of slope formation. These branches of science are not interested primarily in the form that comes into existence as a result of processes. Engineers and agricultural experts investigate, e.g., the effect of a specific technical or agricultural intervention.

Geography and more specifically geomorphology has investigated several aspects of slope formation by applying widely differing methods. It is also right to expect a great variety of methods, since the exploration of the laws of slope development is a hard and complicated task. The combined effect of a great number of factors must be analysed and evaluated in a complex way. Here we do not wish to enumerate the methods applied in the course of different investigations: we only want to draw attention to a solution — intended to be an experiment — that could contribute to the solution of the above mentioned problem. This method is the investigation of soil profiles.

The problem of the investigation of slope profiles may be discussed in both an inductive and a deductive way. This latter approach is concerned with the general theory of the formation of slope profiles, while the inductive method draws its conclusions from an analysis of a great number of slope profiles examined in the field. We have adopted the inductive approach in our investigations.

## A BRIEF DESCRIPTION OF THE METHOD OF SLOPE PROFILE ANALYSIS

A detailed morphometric field survey of slopes (by means of theodolites) on rationally selected different slope segments is completed. The next step is a comparison of the profiles plotted from detailed topographic maps, and also

with the information available from local profiles and exposures in the field. The final aim of the investigations is to establish — on the basis of morphometric analysis of numerous slope profiles and the investigation or the evaluation of several borehole data of field surveys — the processes that are responsible for the formation of individual slope profiles.

Several authors have dealt with the problem of slope profile analysis. We mention, in particular, the relevant works of A. N. Strahler, R. A. G. Savigear and A. Young. A common feature of the works of these authors is that they discuss the morphometric and mathematical aspects of the problem and pay less attention to the relationship between form and process.

The following problems arise in connection with the survey of slope profiles: 1. field of investigation, 2. selection of the site of profiles, 3. selection of length of slope profile.

## 1. FIELD OF INVESTIGATION

Before marking the site of profiles in the field, we must, first of all, decide what kind of slopes may come into consideration. Our attention is centered on the slopes of plains, hills, or submountainous areas built of loose (mainly loessy-sandy) sediments, formed chiefly by derasional activity and presently under cultivation. This delimination implies that in the course of the present investigation of our area generally we have concentrated on the analysis of slopes with a relatively small inclination and a longer profile. We did not deal, however, with short and steep slopes mostly formed by slope-mass movement. These latter form the subject of our current special investigations and the relevant results will be published in separate studies.

## 2. SELECTION OF THE SITE OF PROFILES

This is an important question because slopes are surfaces, thus their study as a plane section perpendicular to sea level is a simplification that depends greatly on the selection of the site of a given slope profile. A further requirement is that profiles should follow the direction and trend of the greatest inclination of slopes. The surface is often so uneven that in the course of field measurement as well as while plotting from a map it is nearly impossible to mark accurately the direction of the greatest inclination. Thus it seems most effective to mark slope profiles in those places where contour lines run roughly parallel to each other (Strahler, 1956). An additional problem arises if the greatest inclination suddenly changes direction (A. F. Pitty, 1966). It may lead to further inaccuracy if the dense vegetation or tall buildings found along the profile force us to make a detour while surveying.

Two solutions are possible when profile sites are selected: either we choose the profile that appears to be the best and most suitable, or we select it according to some statistical principle, at random. This latter solution seems to be more reliable and more exact, though we have to reckon with the fact that in this way unwanted profiles become part of our series, besides the above mentioned difficulties (vegetation, buildings) that may disturb the survey. Thus it is more convenient to mark the profile sites on the basis of field prospecting. In the course of our survey of about 60 profiles, we have adhered to this principle.

## 3. DETERMINATION OF THE LENGTH OF PROFILES

Slope profiles may traverse several valleys and ridges, and may run as far as the boundary of the area studied. In practice it is usually the profiles of a given valley-side which are selected: thus we measure from the valley bottom

to the watershed. The profiles of a valley or ridge can be studied from time to time. It is doubtful, however, if the boundary of a form-group with similar genesis may be drawn at the watershed, which we have selected as an arbitrary boundary for our profile. Furthermore it is difficult to mark the watershed accurately.

There are various propositions on how to determine the length of slope profiles. The upper boundary of the profile should be drawn in every case in the field, according to its exact orographic position.

After these preliminary remarks, we would discuss the conclusion that can be drawn from the examination of these surveyed slope profiles.

The necessity of the use of theodolites in field surveys is well justified by the difference that exists between field surveys and profiles plotted from topographic maps. The differences revealed by the comparison of field surveys and profiles plotted on the basis of detailed topographic maps show the microforms of slopes (Figure 1). Thus the morphometric field surveys show the slight unevenness, steps, steep sections within short distances, crevices, small concave and convex sections of slopes, while these are not recognizable on mapped profiles. The occurrence and frequency of micro-forms affect the nature of physical processes acting on slopes, they alter the general process of development, and influence slope formation as a whole.
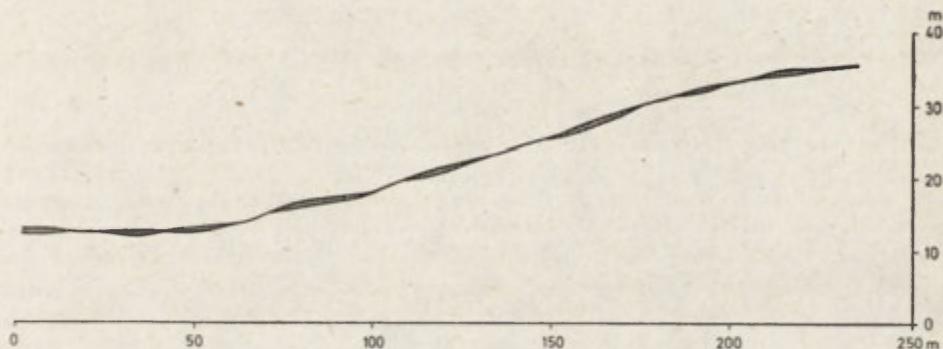


Fig. 1. Slope profile on the Majdán-plateau in a WSW–ENE direction
Shaded sections indicate the differences between the data obtained from maps and the data obtained from measurements in the field. Vertical exaggeration is 2×.

The above mentioned micro-forms can be — depending on ecological conditions — eliminated as a result of anthropogenic activity, but at the same time they may develop further and become indicators of renewed diversified slope development. In spite of the limited extent of their influence at present, their inclusion is well justified.

On the basis of the evaluation of morphometric profiles it is possible to separate the individual types of slopes presently infuenced by anthropogenic activity. This is of special importance, because up to now slopes have been classified merely into a few basic forms, and even detailed analyses do not show to what extent these basic forms are combined, in what order and ratio etc. do the convex, concave, and straight slope sections alternate. The knowledge of the above is very essential concerning future slope development and in assessing the favourable and unfavourable endowments of slopes, so that they are used optimally.

On the basis of our slope-profile investigations, still in the initial stage, we have observed the following:

1. The slope sections of several slope profiles plotted from detailed maps can be characterized by concave curves, while they appear in the field surveys as various combinations of convex, concave and straight parts (Figure 2). The ratio of convex and straight sections within the profile recorded as generally convex was 55–60 per cent. In these cases no depositional tendency asserts itself and degrading neutral and accumulating sections alternate along the profile. Looking for the cause, we find that in these profiles there occur frequent but mostly secondary dissections of relief. Apart from this, the above mentioned profiles serve as an example of how far field investigations modify former more general conclusions.
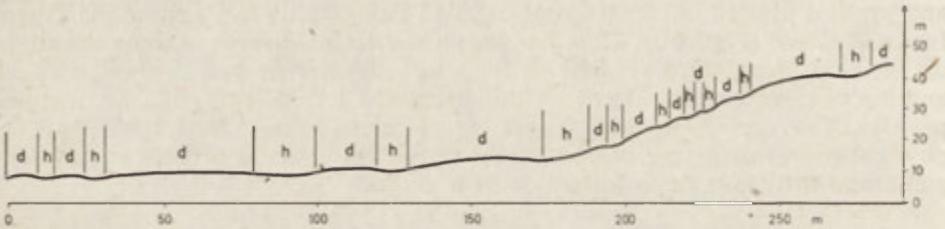


Fig. 2. Slope profile on the Farkas-mountain on a SW-NE slope
d — convex slope segment
h — concave slope segment

Besides this, detailed profile investigations brought to light that on the concave, lower parts of slope sections the rate of accumulation is not always proportional to the size and degree of degradation of the slopes. In several profiles there was scarcely any accumulated soil material on these concave strips. This may be due to several causes; in most cases it simply means that the zone of accumulation is a narrow strip and the bulk of the fine-grained sediment — degraded from the upper segments of the slopes — is washed directly into local channels and is thus transported further downslope. In some cases — mostly in wind grooves — deflation also plays a role in the translocation of material.

2. The straight and steeper slope segments or the gradually sloping segments plotted from maps were primarily gently convex slope sections on the basis of field investigations, and intermediate small depressions with gently
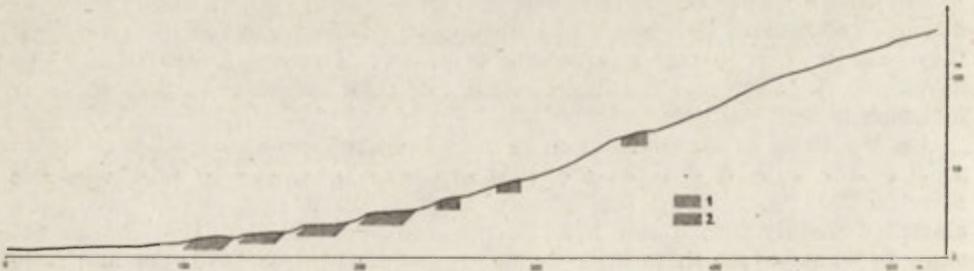


Fig. 3. Slope profile on the Negyokros hegy on a NNW-SSE slope
1 — well marked steps
2 — hardly noticeable steps

convex sections occurred only secondarily (Figure 3). Where these latter were frequent, degradation was greatly restricted and even on the intermediate convex sections was confined to narrow strips.

3. Slightly convex or straight slope segments are dominant in about 70–80 per cent of cases characteristic of these steps. Concave profiles occur very rarely, they are generally confined to the narrow upper strips of these "landings", where they are connected to the steeper profiles or may be limited to small depressions. Some of the material degraded from the upper levels accumulates on these steps. This typical feature of these steps may be due to the fact that these forms are mostly stable surfaces though slightly eroded. The almost intact soil profiles indicate a state of equilibrium in degradation and accumulation. The slightly convex curve of the profiles seems to indicate that the percentage value of the eroded material transported to the landings from the upper slope sections is roughly identical with the amount eroded from there.

4. The steepest strips of the slopes that are either straight, or slightly convex or concave curves, represent those sections that are the most intensively degraded and are presently developing. The soil-forming rocks are found mostly near to the surface or else thin cultivated soils are typical.

Connected with the intensive degradation of these slope segments is their high mobility and the fact that they change their site, depending on local factors, quite frequently towards shifting the top levels. On the basis of detailed profile investigations and mapping (S. Marosi, J. Szilárd, 1969), the manner in which these steep slope segments move on the slopes, can be described. On the slope segments that were formally eroded down to the parent material and later abandoned by the steep retreating slope sections, recently formed culture soils are found. These culture soils of differing character and thickness lying on the lower parts of the now moderate slopes indicate the direction of movement along the slopes. At the same time, towards the top levels the gradually thickening soil profile testifies to a reduced degradation in the direction of movement as the slopes become less steep. This phenomenon may recur — depending on the nature of the slope — at several sites. It occurs not only along the longitudinal slope profile, but also spreading sideways at several sites, depending on the dissection of the slope.

5. On the basis of 36 representative soil-profile analyses taken in the foregrounds of the .Buda Mts. and the Velence Mts., and in the hilly region of Somogy we were able to conclude that the longest slopes were measured on pediment surfaces, and the relatively shorter ones on the uplifted marginal areas. The length of slope ranged between 94 and 570 m. On the basis of present data concernig the relationship between the length of soil profiles and the height of slopes, we may establish that the average inclination of long-slopes is smal-
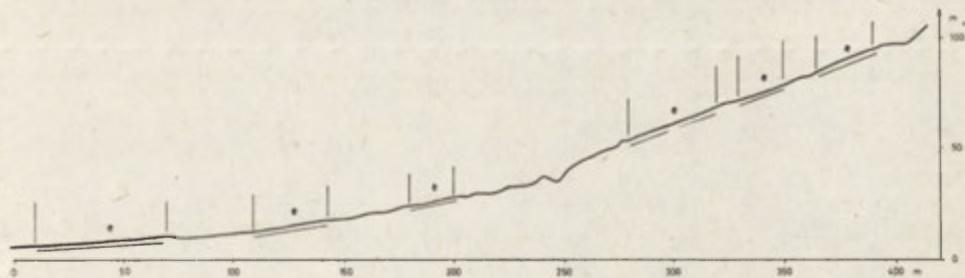


Fig. 4. Slope profile on the Farkas-mountain on a NNW-SSE slope
e — straight slope segment

ler. In the case of slopes shorter than 200 m, where the triangle is constructed from the base of the slope and the height of the slope, the average value of the cotangent of the angle with the base of the slope was 6.89, while this value changed in the case of slopes longer than 200 m to 9.57.

We shall carry on with these investigations in the future. A much larger number of profiles have to be surveyed in different areas for the statistical analysis of morphometric data. Thus the value of the generalizations will be greater and the formation of types will be possible. The recognition and analysis of these types can serve as the basis for an optimal economic use of slopes.

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# THE ROLE OF LAND USE IN VARYING THE SUSPENDED LOAD DURING CONTINUOUS RAINFALL (KAMIENICA NAWOJOWSKA CATCHMENT, FLYSCH CARPATHIANS)

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The Carpathian river valleys experience catastrophic floods every few years. Floods are the result of continuous rainfall with daily amounts exceeding 100 mm (T. Niedźwiedź, 1972). Floods play the major role in channel transformation and they are moving waste materials accumulated in the valley-floors at flood-free intervals (K. Brykowicz et al., 1972; W. Froehlich, 1972; M. Gałka, 1973; M. Klimaszewski, 1935; M. Niemirowski, 1972; L. Starkel, 1972; M. Woźnowski, 1935; A. Zierhoffer, 1935; T. Ziętara, 1968, 1974). Both intensity and magnitude of the waste removal process is reflected in the suspended sediment transport. During floods the Carpathian rivers can carry more than half of the material transported per year (J. Brański, 1968; J. Cyberski, 1969; W. Froehlich, 1972; Z. Kajetanowicz, 1938; A. Welc, 1972; H. Ziemska, 1928). For this reason, detailed studies of the then removed material are necessary to know the extreme intensities of the present-day waste removal from the Carpathian flysch catchments.

Both the activities of man and land use affect the transport of materials by rivers (J. Douglas, 1967). Researches into the mechanism of sediment transportation during floods and of waste supply from the small catchments with various land use have as yet been lacking.

## PURPOSE AND METHODS OF STUDY

The paper includes the author's preliminary results of continuous measurement of sediment carried by the river Kamienica Nawojowska and its tributaries: the Krysciow and the Homerka (Fig. 1). The purpose of study is to explain the influence of land use on the variation in both waste supply and waste removal from the Krysciow and the Homerka drainage basins (compared to the Kamienica Nawojowska catchment) during the 1972 flood.

Measurements were made of the water turbidity in the hydrometric sections at the stream mouths. During the flood, 1 litre water samples were collected from the current by dip-bottles at intervals of 1-2 hours. The suspended sediment concentration was determined by filtration and weighing.

Fig. 1. Map of the study area

1 — river system, 2 — watersheds, 3 — forest, 4 — height spots, 5 — meteorological stations,
6 — rain gauges, 7 — limnigraphs, 8 — water gauges

THE STUDY AREA

The Kamienica Nawojowska catchment of 239 km² is situated in the eastern part of the Sącz Beskid Mts. and it rises to between 280 and 1084 m a.s.l. The drainage basin as a whole consists chiefly of the flysch (sandstone-shale-marl) Magura series. Only in the north-western part of the area, i.e. in the Sącz Basin is a complex of Miocene clay and sand overlain by Quaternary alluvia. The Kamienica Nawojowska valley comprises both gaps cut in solid rock and basin-like widenings filled with fluvial gravel and boulders. Those conditions, together with the irregular valley gradients tend to favour sediment supply and removal.

The land use pattern in the Kamienica Nawojowska catchment is related to both altitudinal zonation and relief types. In the Beskidian high-mountain zone of steep slopes and skeletal mountain-soils woodland is predominant. Forest occupies some 35.6% of the catchment area. In this zone the narrow and forested (in 82%) Kryściów drainage basin of 7.03 km² is situated (Table 1). The narrow valley floor and the steeply inclined valley- and hill-sides are unfavourable for settlement and farming. In the low-mountain and high-foothill zone arable grounds occupy 35.6% of the Kamienica Nawojowska catchment. Slopes contain deep loamy-silty waste mantles with a small admixture of sharp-edged debris. Their liability to washing shows seasonal variations. It depends on the compactness of the soil aggregates and on the moisture content.

TABLE 1. Characteristics of the geographical environment of the catchment basins

| Catchment basin | Area (km²) | Height above sea-level (m) | Length of river (km) | Gradient of river (‰) | Drainage density (km/ /km²) | Road density (km/ /km²) | Land use (%) | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | | | | forest | meadow and pasture | land under cultivation |
| Kamienica Nawojowska River | 239 | 1082–280 | 32.2 | 18.1 | — | — | 42.7 | 8.7 | 35.6 |
| Homerka Stream | 19.55 | 1060–370 | 10.7 | 57.0 | 2.60 | 4.6 | 51.8 | 7.0 | 38.2 |
| Kryściów Stream | 7.03 | 1082–520 | 7.1 | 53.3 | 2.41 | 2.2 | 82.0 | — | — |

In the wide Homerka drainage basin (19.55 km²) intermediate and high foothills are common. Arable grounds (38.2% of the area) extend far into the Homerka valley. Forest covers 51.8% of the area and is mainly concentrated in the headwaters. In the Homerka basin, the land use pattern and the proportions between cultivated area and woodland are similar to those in the Kamienica Nawojowska catchment.

In the latter one woods are intensively exploited now and show a dense network of roads and timber tracks. These are responsible for a diminution of flood control by forest. Furthermore, they are the source areas of great amounts of fine waste transported in suspension. In areas under cultivation the patchwork of fields is associated with a grid of roads. Apart from the field furrows, roads increase the natural drainage density. They also accelerate the water cycle in the catchment and provide abundant waste (K. Figuła, 1960, 1966; P. Prochal, 1958; J. Słupik, 1973; W. Froehlich, 1975).

Shape and size are essential parameters by which both drainage basins differ. These parameters determine both lag time and flood wave concentration. Although attempts have been made to explain the influence of basin shape in a theoretical way (A. N. Strahler, 1964) this problem has as yet not been studied in the Carpathian catchments.

## THE HYDROLOGICAL REGIME OF THE KAMIENICA NAWOJOWSKA

The Kamienica Nawojowska drainage basin receives on an average 872 mm of precipitation per year. Rains are most intense during the summer. Single downpours which occur every few years may exceed 100 mm per 24 hours and produce catastrophic floods. In the winter snowfall occurs.

The Kamienica Nawojowska is a typical Beskidian river with a rain—snow—ground regime of supply. Its annual mean discharge at Nowy Sącz was 3.4 m³/s in 1961–1970, and it oscillated from 1.9 m³/s in 1961 to 5.5 m³/s in 1970. In the autumn and winter, during very low water discharge falls below 0.5 m³/s. Spring peak discharges caused by snow melt reach as much as 70 m³/s. Maximum discharges recorded during catastrophic floods which occur every several years may exceed 300 m³/s (W. Froehlich, 1975).

At low stage the Kamienica Nawojowska carries 2–8 g/m³ of fine waste. The suspended sediment concentration increases many times during violent river floods caused by excessive rainfall and it may exceed 13 kg/m³ (on 19 July, 1970). With similar flood discharges, the river can carry varying suspended loads (W. Froehlich, 1975).

## THE HYDROLOGICAL CHARACTERISTICS OF FLOODS

The flood of August 1972 was the result of continuous rainfall lasting from 19 to 23 August. Rain gauges installed at the outlet of the Kryściów and Homerka catchments recorded a total precipitation of 115 mm then (Table 2). The daily precipitation total at the Kryściów mouth was 70 mm on 20 August. This equals to some 12% of the annual precipitation total. The magnitude of the flood described was much lower than that of the catastrophic flood which occurred in the Carpathians in July 1970. The parameters of both floods are contained in Table 3.

During the flood described streamflow began to rise on 20 August. A direct run-off response to the rainfall was produced in the catchments of the

TABLE 2.   Hydrologic parameters of the rainfall floods of July 1970 and August 1972

| Catchment basin | Maximum discharge (m³/s) | | Specific run-off (m³/s) | | Run-off from basin (m³) | |
|---|---|---|---|---|---|---|
| | 1970 | 1972 | 1970 | 1972 | 1970 | 1972 |
| Kamienica Nawojowska River | 314 | 187 | 1,314 | 782 | 38,183,000 | 23,960,448 |
| Homerka Stream | — | 15.12 | — | 773 | — | 1,445,126 |
| Kryściów Stream | — | 5.60 | — | 797 | — | 513,646 |

TABLE 3. Parameters of the suspended sediment transport during the rainfall floods of July 1970 and August 1972

| Catchment basin | Maximal turbidity (g/m³) | | Total amount of suspended load (t) | | Mass of suspended sediment (amount per 1 sq. km) | |
|---|---|---|---|---|---|---|
| | 1970 | 1972 | 1970 | 1972 | 1970 | 1972 |
| Kamienica Nawojowska River | 13,498 | 9,188 | 285,769 | — | 1,196 t | 195 t |
| Homerka Stream | — | 9,630 | — | 2,154 | — | 110 t |
| Kryściów Stream | — | 4,292 | — | 366 | — | 52 t |
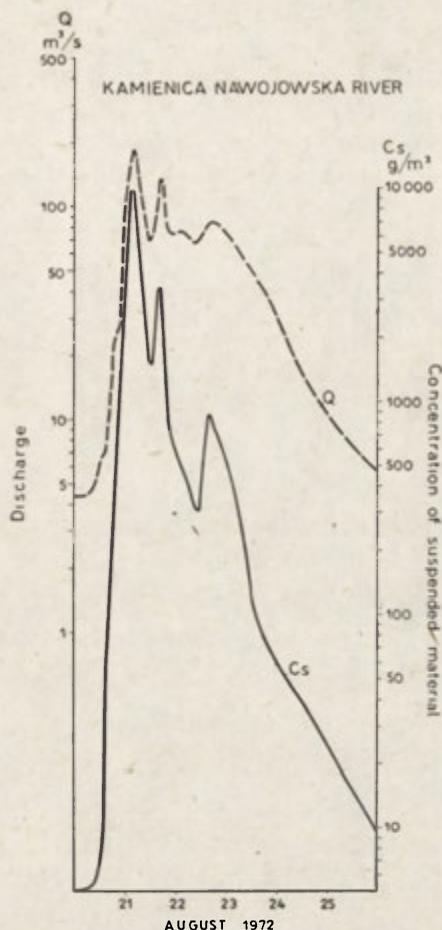
Fig. 2. Diagram of changes in stream discharge (Q) and suspended sediment concen·
tration (C$_s$) during the flood of August 1972 in the Kamienica Nawojowska River

Kryściów and the Homerka. A few hours later discharge increased at Nowy
Sącz on the Kamienica Nawojowska (Figs 2, 3 and 4). Changes in water level
recorded by limnigraphs coincide with those of rainfall intensities. The flood
wave consisted of several peaks. Discharges reached their maximum in the
morning of 21st August: 187 m³/s (782 1/s/km²) on the Kamienica Nawojowska;
15.12 m³/s (773 1/s/km²) on the Homerka; 5.60 m³/s (797 1/s/km²) on the Kryś-
ciów. Although 82⁰/o of the area is forested the specific run-off in the Kryściów
catchment was much higher at peak flow than that in the drainage basin as
a whole. This suggests that the small basin width and the very dense network of
both natural and artificial incisions brought about the shortening of lag time
and flood wave concentration. Compared with the Homerka drainage basin,
the rapid run-off was not reduced in woodland. The only effect was that the
streamflow was falling more slowly in the final phase of the flood there
(Fig. 4).
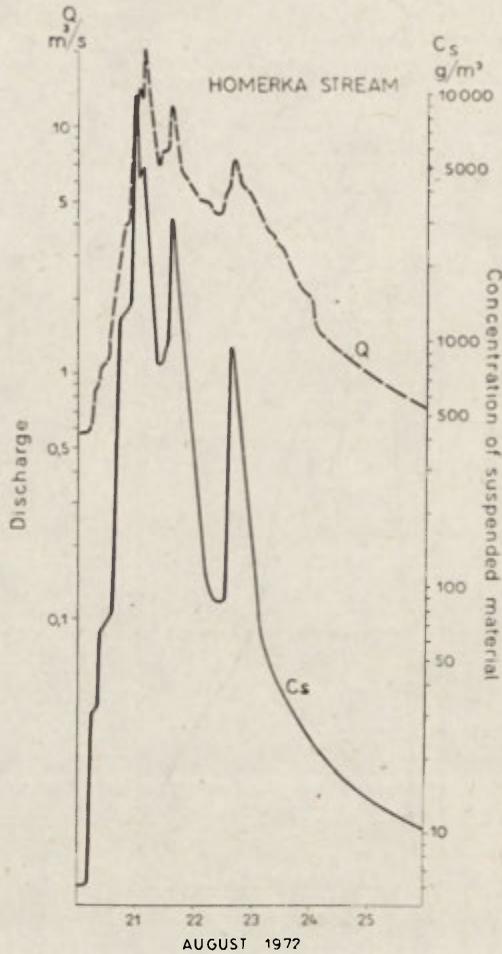
Fig. 3. Diagram of changes in stream discharge (Q) and the suspended sediment
concentration ($C_s$) during the flood of August 1972 in the Homerka Stream

## THE REMOVAL OF FINE WASTE IN SUSPENSION

During the flood, the course of changes in suspended sediment concentra-
tion reflected the flood wave shape. Cn the streams Kryściów and Homerka
the peak suspended sediment concentration (turbidity) occurred before the
corresponding streamflow peaks. This situation is related to the increased slope
wash and rapid material supply by the network of artificial incisions adjacent
to the stream channels.

n the Kamienica Nawojowska the maximum turbidity of 9188 g/m³ and
the maximum discharge of 187 m³/s coincided. This can be explained by the
combined effect of the first flood waves that were contributed by the small
catchments, and by the increased sediments production in the stream channel
which became adjusted to the hydrodynamic conditions of the bankfull stage.

The peak suspended sediment concentration observed on the Homerka was
9630 g/m³. This value approximates to that for the Kamienica Nawojowska
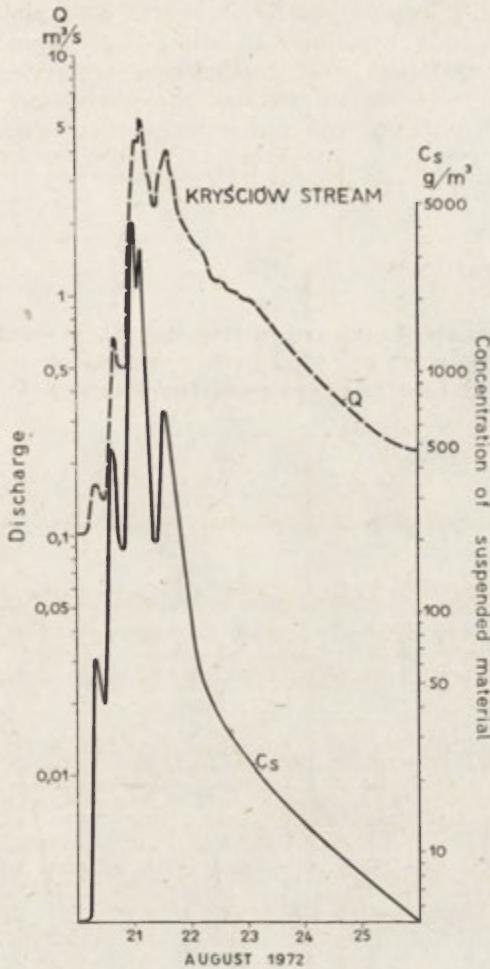
Fig. 4. Diagram of changes in stream discharge (Q) and suspended sediment concentration ($C_s$) during the flood of August 1972 in the Kryściów Stream

(9188 g/m³), whereas on the Krysciow the peak suspended sediment concentration was only 4292 g/m³.

It appears that with similar discharge, the rivers examined carry different suspended loads. The shape of the turbidity loop reflects the conditions under which the fine waste is provided for transport in suspension (Fig. 5). These loops include a distinct rising limb (rising flow) and a falling limb (recession flow). The different width of the loop can be explained in terms of the varying supply of fine sediment in the various phases of the flood.

Narrow turbidity loops for the Kamienica Nawojowska and the Homerka indicate that conditions were favourable for the increased supply of waste in the various phases of the flood. Such conditions prevail in the lower lying cultivated areas. The greatest amounts of sediment are provided by the dense network of roads reflecting the pattern of land ownership. This is responsible for the high values of suspended sediment concentration in the rivers Kamienica Nawojowska and Homerka.

The broad turbidity loop for the Kryściów can be explained in terms of the retarded sediment supply, especially at falling stage. This may be due to the protective role of forest which reduces both surface run-off and slope wash. In the rock-cut Kryściów stream channel the production of fine material is confined to the short phase of bed load transportation, whereas the wide accumulational channel reaches of the Kamienica Nawojowska and the Homerka provide great amounts of fine waste.

## THE TRANSPORT BALANCE

The volume of sediment removed in suspension represents the sum of transported materials that were recorded in the various phases of the flood. The amount of suspended load removed from the Kamienica Nawojowska catch-
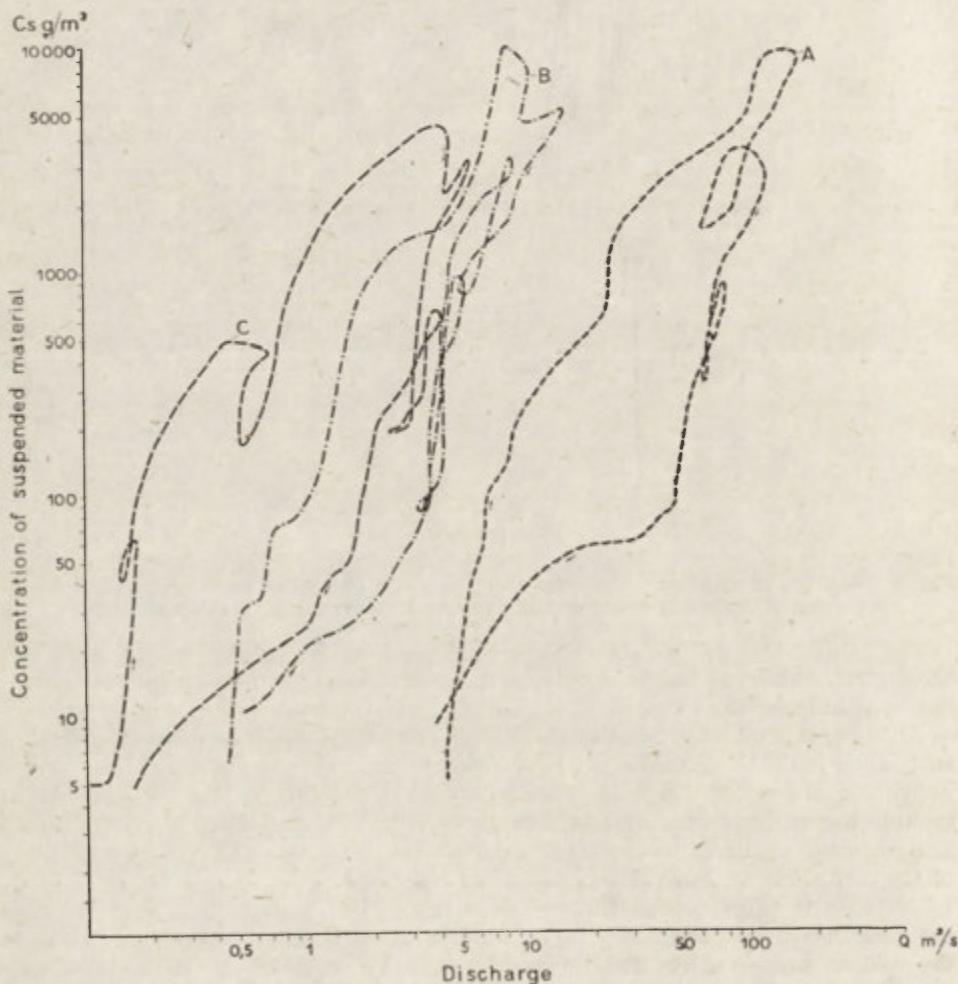


Fig. 5. Diagram of changes in the concentration of suspended material ($C_s$) in relation to the discharge ($Q$) during the flood of August 1972 in the:

A — Kamienica Nawojowska River, B — Homerka Stream, C — Kryściów Stream

ment was 41,533 tons (174 t/km²). 2,154 tons (112 t/km²) were removed along the Homerka stream channel, and 366 tons (52 t/km²) of fine material were taken away from the Kryściów catchment.

More than 95⁰/o of the suspended sediment removed by the flood were transported in its early phase which comprises 40⁰/o of duration. It appears that waste removal from the drainage basins of mountain rivers is most intense at rising stage. In plans for reservoir constructions and hydrotechnical developments on the streams considerations should, therefore, be taken of the extreme values of sediment transported in the early phase of the flood. The frequently cited annual mean values can be exceeded many times during a single flood.

Results show that in the Kamienica Nawojowska catchment the removal of waste takes place with varying intensities. Differences are clearly important when the amounts of material removed per unit area are being considered in the different drainage basins. The small amounts of material taken away from the Kryściów basin show that the waste removal process is retarded in woodland. Its protective role is both diminished and masked by the dense network of artificial incisions.

At present, the activities of man and land utlilization clearly influence the course and intensity of waste removal from the Carpathian flysch catchments.

According to K. Klimek et al. (1972), high discharges leading to violent flooding may have been influenced by deforestation of the Carpathian drainage basins. This is indicated by the high frequency of coarse fractions of sediment forming the river mud in the Wisłoka valley. Studies by M. Niemirowski (1972) also revealed that the intensity of the present-day processes of erosion is lower in well forested catchments compared with those where cultivated areas are predominant.

CONCLUSIONS

In the Kamienica Nawojowska catchment floods can remove more than 70⁰/o of the waste transported in suspension per year. In the early phase of the flood which comprises some 40⁰/o of duration more than 95⁰/o of the suspended sediment is being removed. During the flood described the Kamienica Nawojowska carried away 46,537 tons of fine waste which equals to 195 t/km². On the contrary, in the forested (in 82⁰/o) Kryściów catchment and in the cultivated (in 38⁰/o) Homerka catchment the corresponding values are 48 and 51 t/km². The high values of waste removed from the entire Kamienica Nawojowska catchment is due to many features. These include the high production of fine material immediately in the accumulational channel reaches, abrasion of transported material and processes of erosion. For this reason the effects of present-day waste removal during floods supported by measurement on the large rivers should not be extrapolated to the small drainage basins.

Both the course of hydrological phenomena and the rates of waste removal from the Kryściów and Homerka catchments suggest that at present it is the various density of artificial incisions (resulting from intense cutting of woods and farming) which essentially influence the above process. Crowded together artificial incisions are typical of the flysch Carpathians (J. Słupik, 1976). Man influences the intensity of waste removal during floods through a dense network of artificial incisions rather than removal of forest. As a consequence, the natural stream densities are increased and the water cycle in the catchments accelerated. Furthermore, great amounts of material are supplied to the rivers. Thus, the protective role of forest is being reduced. In the Kryściów catchment

the low values of maximum suspended sediment concentration and the limited waste supplies into the stream channel are indicators of the distinct influence of forest.

Because of the different basin shapes a firm estimate of both influence of land utilization and magnitude of waste removal during flood is not possible. The basin geometry determines lag time and flood wave concentration. It also may diminish the protective role of forest. For this reason, future hydrotechnical undertakings should pay more respect to basin shapes and land utilization, and to the extreme values of waste removal as well.

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# REGULATED RIVERS IN HUNGARY

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## I

The Hungarian river-system, developed within the Pannonian or Carpathian Basin, one of the geosynclinal areas of the Earth, is undergoing a very intensive transformation today. Besides the larger rivers shown in Table 1, there are about 2500 water courses including the smaller ones in Hungary. Their total length amounts to 26,400 km, with a stream-density of exactly 0.27 km/sq. km. Areal distribution is uneven, depending on the amount of precipitation, the permeability of the surface and on the inclination.

A high proportion (about a quarter) of the area of Hungary (shown in Figures 1-3) would under natural conditions be constantly or at least periodically inundated. This can be explained by the history of the surface processes. The prevailing hydrographic conditions are due to the subsidence of the Great and Little Plains and of some areas in Transdanubia, from the Late Tertiary and continuing into the Holocene. The marginal depressions were responsible for the rapid transition of the rivers from their mountainous reaches to the plains. Their gradient decreasing, they were forced to deposit their alluvium, forming a series of alluvial cones and meandering around these, without any fixed direction. The zones of marginal depressions and alluvial fans were full of poorly drained, slowly infilling closed sub-basins. Owing to the great number of meanders, the actual length of the rivers is many times greater than their length measured from the air.

Due to these circumstances the flood waves that occurred in the mountainous catchment areas due to heavy precipitation piled up in the foreland of the mountains on the Great Plain.

The climate of the Carpathian Basin is such that two floods occur on the rivers — the early spring flood results from the snow-melts, and the early summer flood drains the waters of the annual precipitation maxima — the periodically inundated parts of the flood-plains dry out only in the second half of the year and then they are used for stock-breeding. Social and economic activity was limited from the earliest times to the flood-free surface as proved by archeological data. Increasing social demand at the beginning of the 19th century pressed for flood control and the regulation of the rivers became a national task.

Though there existed similar initiatives for other purposes in earlier centuries only limited and local results were achieved and it was under the leadership of István Széchenyi, President of the National Transport Committee, that

Fig. 1. Map of the drainage system of the Danube and the Tisza river
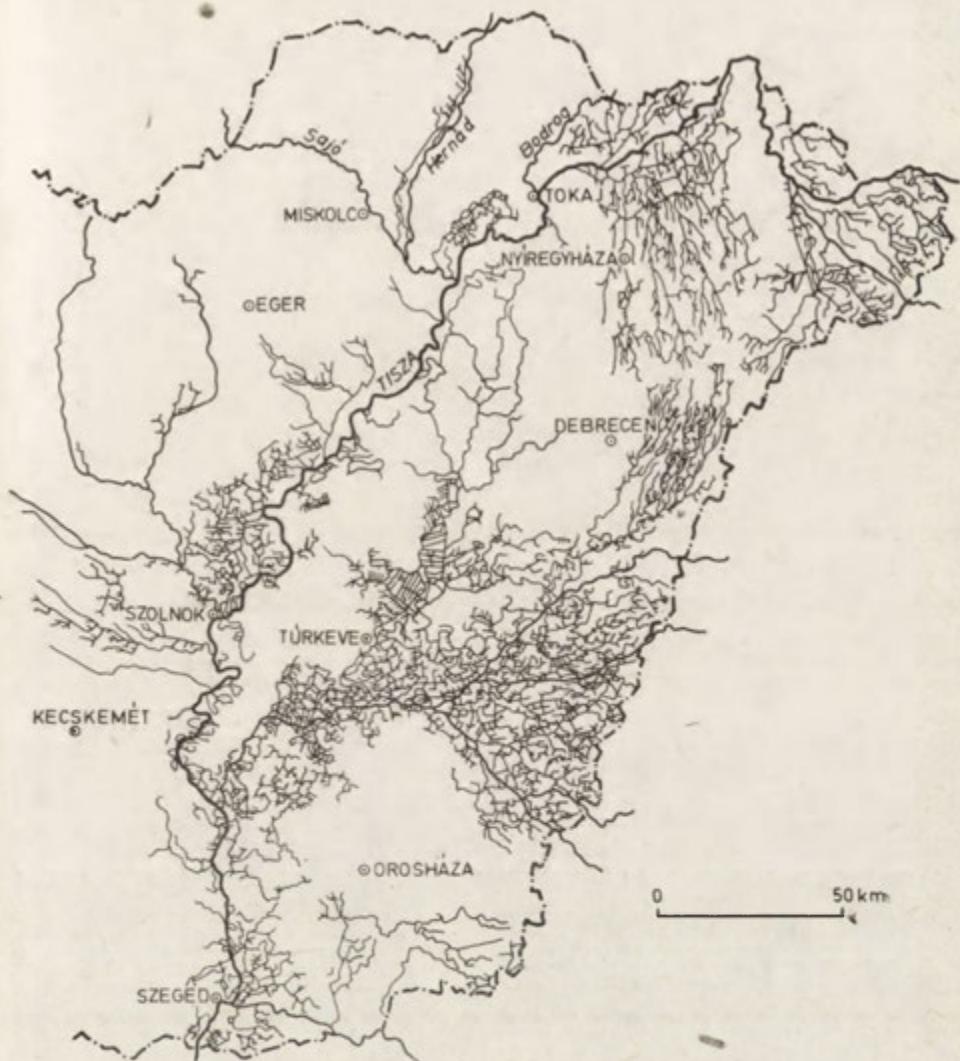
Fig. 2. Hungarian canal system in the area east of the Tisza-river

river control was started with the help of national solidarity and organization, and it was only then that the damage done by rivers could successfully be prevented. Under the leadership of outstanding engineers the works were undertaken in the first decades of the last century and continued until the first World War with impressive results.

The most important data about specific rivers are shown in Table 3, while Table 4 contains data on the Tisza, the river that was altered the most. A more than 600 km long new bed was created, many hundred meanders were cut off and the length of the Hungarian rivers was shortened by several thousand kilometres.

Beside the new river-beds a 3000 km long embankment was constructed for the protection of the reclaimed flood-plains, the total area of which was 23,600 sq. km (nearly a quarter of the total area of the country). In the humid

Fig. 3. Areas frequently flooded in Hungary before the regulation of the rivers
1 — permanently inundated areas; 2 — periodically inundated areas

TABLE 1. The largest rivers in Hungary

| River | Total length in km | Catchment area in sq. km | On Hungarian territory | |
|---|---|---|---|---|
| | | | length in km | catchment area in sq. km |
| Duna | 2,860 | 817,000 | 417 | 93,000 |
| Mosoni-Duna | 120 | 18,061 | 113 | 8,723 |
| Rába | 283 | 10,113 | 191 | 4,550 |
| Ipoly | 257 | 5,108 | 164 | 1,518 |
| Sio | 334 | 14,728 | 334 | 14,726 |
| Dráva | 720 | 40,490 | 160 | 6,378 |
| Mura | 454 | 14,138 | 48 | 1,987 |
| Tisza | 962 | 157,000 | 598 | 47,000 |
| Szamos | 415 | 15,881 | 50 | 306 |
| Bodrog | 267 | 13,579 | 50 | 972 |
| Sajó | 229 | 12,708 | 130 | 4,203 |
| Hernád | 282 | 4,556 | 110 | 1,011 |
| Zagyva | 179 | 5,677 | 178 | 5,672 |
| Hármas-Körös | 363 | 27,537 | 91 | 12,931 |
| Kettős-Körös | 37 | 10,386 | 37 | 1,744 |
| Feher-Körös | 236 | 4,275 | 8 | 298 |
| Fekete-Körös | 168 | 4,645 | 14 | 151 |
| Sebes-Körös | 209 | 9,119 | 59 | 3,155 |
| Berettyo | 204 | 6,095 | 78 | 2,649 |
| Hortobágy | 163 | 5,776 | 163 | 5,776 |
| Maros | 754 | 30,330 | 48 | 357 |

years the inland waters are pumped from the canals with 265 pumps, the total output amounts to 467 m³/s (as much as the average discharge of the Tisza near Tokaj). The volume of water thus removed exceeds the output of the world-famous embankments in the Netherlands. Their effect can be traced for a long way off in the water-courses, in the changes of the natural conditions of the former flood-plains and also in the economic and social life of the population affected.

From among these varied effects, we are in a position to discuss only those that have taken place with regard to rivers. The main aim to be achieved by the building of embankments was to accelerate the run-off, especially at the times of floods by making cut-offs, and the protection both of the former flood-plains that would be used for agriculture and of the nearby settlements. The shortening of the channels resulted in a steeper gradient and in an increase of the velocity of flow. Since run-off became rapid, flood periods were shortened and the duration of low waters were now longer. The narrow flood-plains were restricted in between the embankments so flood levels rose considerably. As a result, the embankment must be raised even today. The steeper gradient resulted in an increase of energy and this led to the incision of the channel-bed and its deepening. The higher flood level resulted in a smaller volume at low water and the embedding of the river channel and in a more extreme water regime. The best example is the change in the water levels of the Tisza river (Table 3, Figure 4).

The reduction of the level of low waters is a consequence of embedding and of the steeper gradient of the shorter channel, with the resultant faster flow

TABLE 2. Data on accomplished river-control works
(after S. Somogyi)

| River | Length of river before and after regulation in km | | Length of cut-offs in km | Number of cut-offs | Length of meanders in km | Average fall before and after regulation in cm/km | |
|---|---|---|---|---|---|---|---|
| Duna[a] | 494 | 417 | — | 23[b] | — | 5.0[b] | 8[l] |
| Tisza[c] | 1419 | 966 | — | 114 | 589 | — | — |
| Tisza[d] | 1211 | 758 | 136 | 114 | 589 | 3.7 | 6 |
| Dráva | 400[d] | 232[d] | 75 | 68[a] | 243 | 7.5[a] | 12[l] |
| Maros[d] | 86 | 50 | — | 13 | — | 14 | 24 |
| Harmas-Körös[c] | 234 | 91 | 34 | 39 | 177 | 2 | 5 |
| Kettös-Körös[c] | 84 | 37 | 23 | 15 | 70 | 4 | 8 |
| Feher-Körös[d] | 126 | 67 | 25 | 81 | 84 | — | — |
| Feketr-Körös[d] | 166 | 90 | 26 | 61 | 102 | — | — |
| Sebes-Körös[d] | 162 | 86 | 53 | 24 | 129 | — | — |
| Berettyó[d] | 269 | 91 | 51 | 46 | 229 | — | — |
| Körösök eqyütt[d] | 1041 | 462 | 212 | 266 | 791 | — | — |
| Szamos[d] | 187 | 108 | — | 22 | 26 | — | — |
| Bodrog[a] | 76 | 50 | 8 | 8 | 34 | 3.5 | 6 |
| Rába[e] | 132 | 84 | — | 80 | 51 | 32 | 47 |
| Temes[c] | 336 | 194 | — | 92 | — | — | — |

[a] Hungarian section; [b] section south of Dunaföldvár; [c] the whole length; [d] regulated section; [e] below Sárvár

TABLE 3. Data on the regulation of the Tisza river

| Tisza | Former length | Present length | Abandoned channel | Length of cut-offs | Short-ening | Fall | |
|---|---|---|---|---|---|---|---|
| | | | km | | % | before regula-tion | after regula-tion |
| Forras—Tiszabecs | 208 | 208 | — | — | — | — | — |
| Tiszabecs—Tokaj | 334 | 208 | 169 | 43 | 38 | 7.5 | 12.2 |
| Tokaj—Tiszafured | 205 | 117 | 113 | 25 | 43 | 3 | 5.2 |
| Tiszafüred—Csongrád | 326 | 191 | 160 | 25 | 41.5 | 2.1 | 3.7 |
| Csongrád—Maros-torok | 99 | 57 | 46 | 14 | 33 | 2.5 | 3.8 |
| Maros-torok—Hatar | 31 | 17 | 19 | 5 | 45 | 1.9 | 2.7 |
| Hatar—Torkolat | 216 | 158 | 82 | 24 | 27 | | |
| | 1419 | 966 | 589 | 136 | 32 | 3.7 | 6.0 |

of water. This has a direct bearing on shipping on these rivers. On the Tisza, for example, before its regulation, ships could sail down to Vásarosnameny without difficulty; after the regulation of the river, however, it could be only periodically navigated even around Szolnok. The navigability of the Maros and the Dráva became impossible. The Danube — with a much more voluminous discharge — was not influenced unfavourably by the moderate shortening of its bed as a consequence of river regulation. The regulated sections retain

TABLE 4. Changes in the water level of the Tisza river

| Water gauge | Changes of low-water level | | Culmination of high waters | | |
|---|---|---|---|---|---|
| | to 1890 | to 1957 | 1830–1855 | to 1932 | to 1970 |
| Vásárosnamény | −140 | −205 | 770 | 832 | 912 |
| Tokaj | −110 | −172 | 715 | 799 | 872 |
| Szolnok | −140 | −227 | 683 | 894 | 909 |
| Csongrád | −150 | −335 | 610 | 929 | 935 |
| Szeged | −130 | −235 | 613 | 923 | 960 |

their dynamic equilibrium and after a certain time try to lengthen their course by developing meanders. The regulated length of the Tisza river has increased from 1890 to 1932 by 5 km. The consequence of the channel deepening and the formation of local meanders was the accumulation of a considerable amount of alluvium. According to estimations, the amount of alluvium deposited by the Tisza, eroding its banks and bed, varied between 60 and 65,000 $m^3/km^2/y$, depending on the intensity of erosion and the resistance of the bed material. The changes are reflected by the shape of meanders, as well, because the erosion of the banks has changed their parameters, too.

The opposite process occurs by the aggradation of the flood-plain as the embankments were built unnecessarily too far from the river. This is proved by the cross-profiles that have been taken in these areas and by the recent alluvial soil covering those flood-plains.

The flood-control measures had the effect of changing the life of the river, and altered the former flood-plains as well. The constant inundation of these latter areas ceased. The periodic floods lasted for a much shorter time and these flood-plains changed as did the natural conditions. The mineralogenic infilling came to an end as a result of the building of embankments. Only the much slower organic or biological processes operate in the area. Thus the former river beds are well-preserved on these higher flood-plains. The several million hectares formerly covered by groves, moors, swamps, marshes and wet meadows became available for agricultural production. On the flood-free embankments there are about 1.5 million hectares of arable nad, 400,000 hectares of pastures and meadows, 80,000 hectares of vineyards and gardens, about 2000 industrial plants, 3000 km long railway lines and 4500 kilometres of public roads, furthermore about 350,000 buildings (Figure 5–6).

In conclusion we would remark that as a result of the large-scale regulation of the rivers and flood-control the former separation of the country into two parts ceased. Thus the two marked regions of flood-free areas and flood-plains that divided the plains into different cultures were eliminated. Human effort with the help of the plough, eliminated in nearly 100 years the territorial differences conserved by nature for thousands of years in the past.

Apart from evaluating the positive effects of river control, we must also refer to the fact that despite their successful implementation, they bear the marks of the capitalist society's approach to the problem. These faults are manifested in the fact that these works only met the demands of mainly passive water management and that of the intervention needed in the given situation. The transitional climate of Hungary is characterized by 3-4 humid years, generally followed by a dry period of 5-6 years. In the first case a great abundance of water, in the latter its shortage may reduce agricultural production.
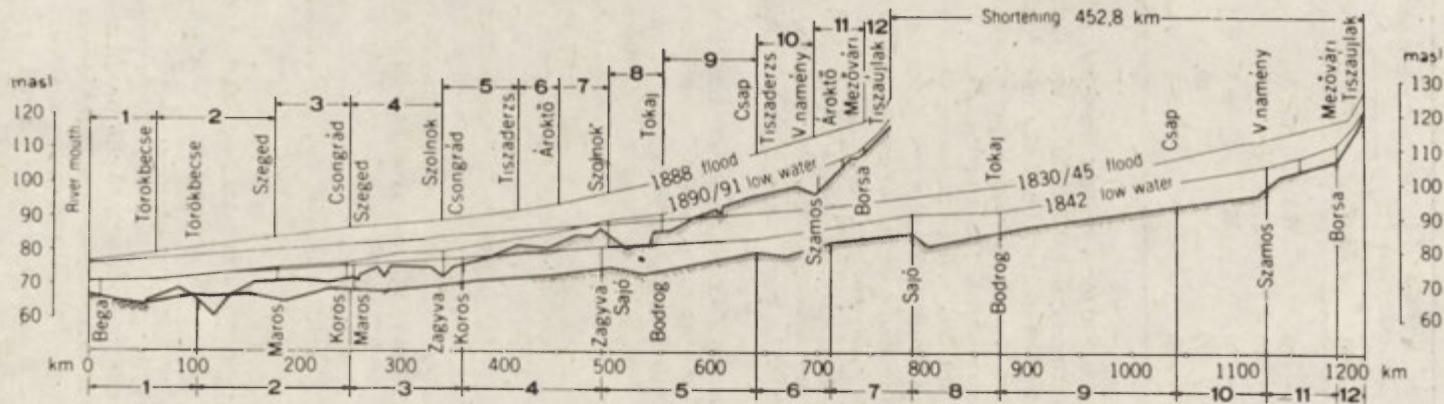
Fig. 4. Longitudinal profile of the Tisza before and after the regulation

Fig. 5. A section of the Danube before and after the regulation

This climatic factor would have required the construction of irrigation canals and reservoirs, the draining of excess waters, furthermore water transport to serve production needs should also have been developed. Apart from some modest initiatives in the period between the two world wars, this could only be realized in the last quarter of the century with the financial backing of our socialist society.

The first important irrigation project was implemented on the Tisza, the Tiszalök Dam — opened in 1955 — that supplies the poorly served areas of the
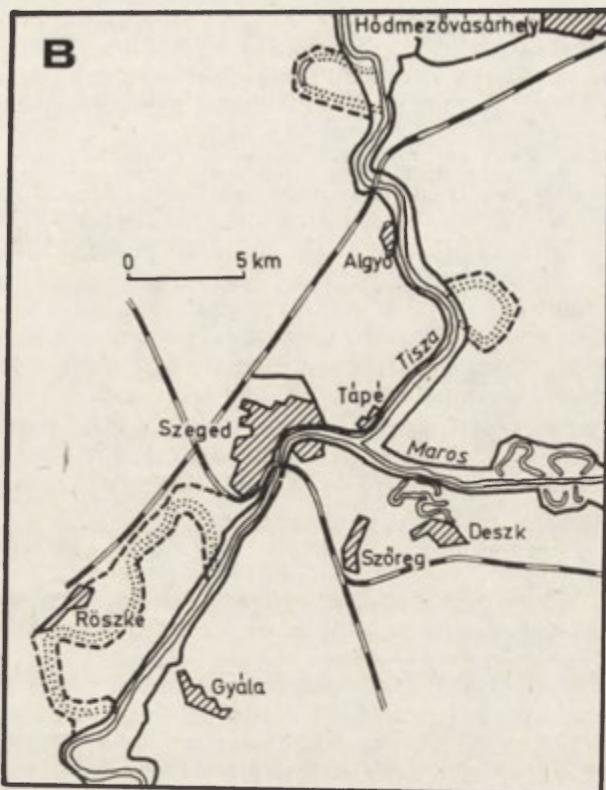
Fig. 6. a–b. The environs of Szeged before and after the river control

Körös rivers with irrigation water from the 108 km long main Eastern Irrigation Canal. The first dam near Bökeny on the Harmas-Körös was built in 1905, the second in 1942 near Bekésszentandrás and the third near Bekés in 1969. This was followed by the opening of the Tisza II Dam near Kisköre. All these serve as reservoirs of irrigation water improving the shipping possibilities in these dammed-up sections. The Tisza Dams provide a modest amount of electrical energy. In addition, the artificial water ponds of 130 sq. km thus created by the reservoir of Kisköre will improve the recreational-sporting facilities of the poorly watered environment. The planning of the third Tisza Dam near Csongrád is already in progress. There are more impressive tasks to be completed on the Danube river. Namely along the section between Bratislava and Gönyü about 5–8000 m³ alluvia are deposited annually in spite of all preventive efforts. This raised the river bed in the last hundred years considerably. Besides, the gradient of the river at this stage is more than 30 cm/km. The interaction between the deposited alluvium and the steep gradient lead to a so-called changing, shifting channel and the formation of alluvial cones. Navigation here even at a sufficient depth of water is difficult and generally needs twice as much energy as that required below Gönyü. It becomes even more difficult and sometimes quite impossible during the usual autumn low-water levels. The Danube is, however, an important waterway. Despite its present limits, the amount of goods transported in 1970 was twice as much as in 1960 and rose from 2.5 million tons to 4.5 million tons. This increase in the

traffic might be explained by the fact that contrary to the arguments of the advocates of road transport, the advantage of river transport lies in its cheapness, i.e., *with one horse-power capacity eight times as much goods can be transported by ship than by train and about thirty times as much·as on public roads.*

The importance of the Danube in national and international flow of goods will grow on the completion of the Danube — Main — Rhine Canal that will be opened in the 80's and it will be followed some time later by the construction of the Danube — Odra Canal now at the planning phase. These international efforts demand large-scale investment and will only be profitable if the navigability of the Danube is improved so that it would become a fourth-class shipping route, with an undisturbed flow of traffic, 1000 ton tow-boats. Apart from these possible improvements the present capacity of 7 million tons in the section between Bratislava and Gönyű cannot be increased.

These requirements can only be fulfilled by the constant artificial grading of the Hungarian section of the Danube, in order that the required depth. of channel for shipping should always be secured. For this purpose, the planning and construction of four dams is in progress :

1. Between Dunakiliti and Bős (Gabcikovo) there is a power station at the water-reservoir created by the damming up of the river.
2. There is a similar power station near Nagymaros.
3. Dams with reservoirs to be built in the near future at Adony and
4. Fajsz.

Once completed these dams and reservoirs would not only form a unified system in terms of hydraulics, navigation and water power, they would serve as an integrated system of water management and as a flood-control device. They ensure the supply of irrigation water for the nearby areas (Figure 7).

The waterways of the Danube and Tisza are supplemented by the Danube — Tisza Canal, which is to provide water for the southern Tisza valley, the water coming from the Danube (100 m³/s) ; furthermore it will link the shipping routes of the Danube and Tisza. We may reckon in the near and distant future on the establishment of further water management projects along the tributaries of the Danube and the Tisza. From among these we only mention the construction of the Sió-system that compensates for the 20 cm difference in the level of the Danube and Lake Balaton with 5 locks, the first a flood-sluice-gate at the outlet — an imposing, but at the same time difficult task that requires large-scale investment by the Hungarian economy in the near future.

All these water management projects, some already completed, others still being built and planned, have and will have effects on the life of the rivers. We only mention a few of these expected changes.

1. With regard to the channel development, the following consequences are to be expected: the common after-effect of the building of dams on the Danube and the Tisza will result in *the movement of the water slowing down.* One must therefore reckon with a greater deposition of sediments moved by saltation and of suspended load in the river section behind the dams. The situation in the Upper Danube will change in as far as the present deposition in the whole section will take place in the reservoir behind the dam at Dunakiliti, and from where it can easily be removed. Below the dam, the rivers will be relatively poor in load  and the river may cut into its bed to some extent, in both the natural and artificial channels and in the former bed now used only to drain flood-waters. These sections must be protected against unfavourable bed erosion.
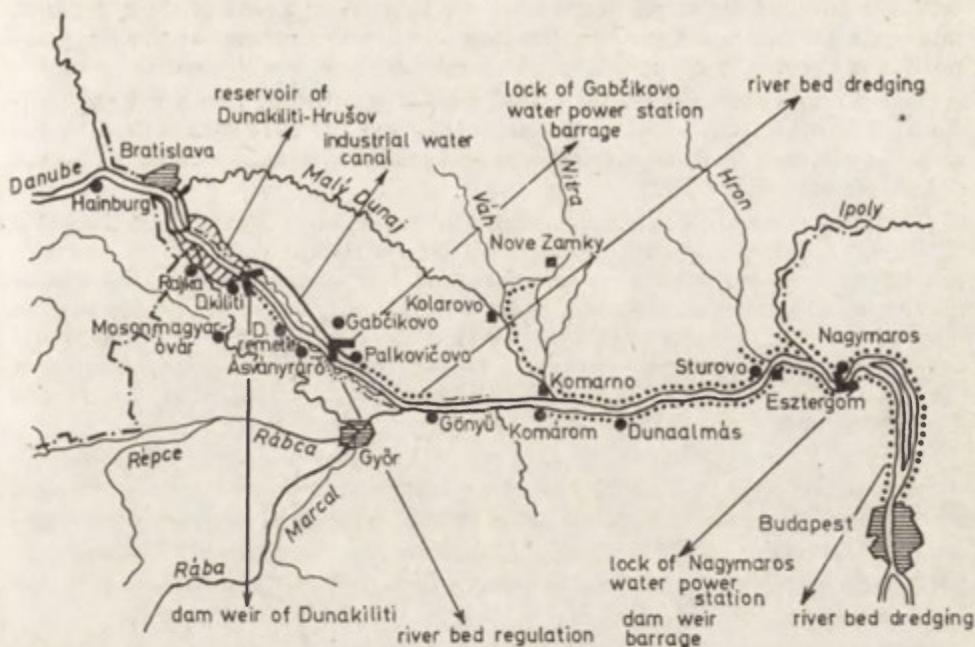
Fig. 7a. Draft of the dam-system at Gabčikovo — Nagymaros (From *Vízügyi Közlemenyek*, 2, 1974)

1 — reservoir near Dunakiliti; 2 — dam near Dunakiliti; 3 — canal for industrial water; 4 — dam, power station and lock-sill near Gabčikovo; 5 — dredging and regulation of the river bed; 6 — dam, power station and lock-sill near Nagymaros
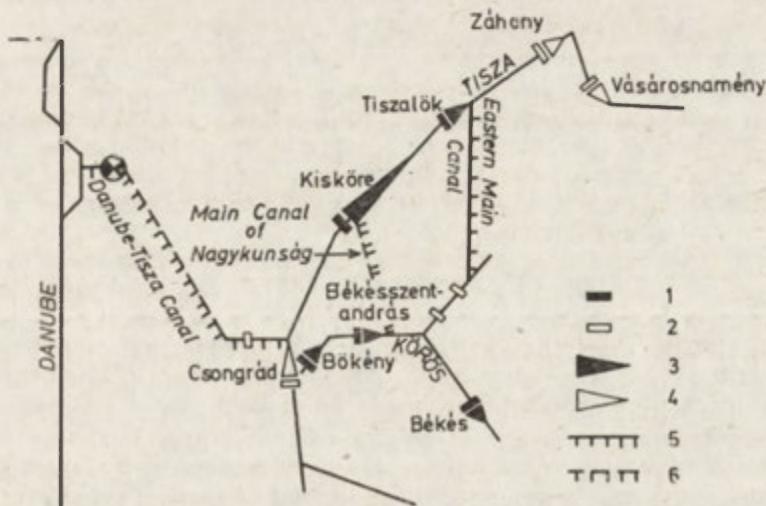


Fig. 7b. Draft of the establishments of water management in the Tisza-valley (From *Vízügyi Közlemények*, 2, 1974).

1 — dam already in existence; 2 — dam planned; 3 — reservoir already in existence; 4 — reservoir planned; 5 — canal already completed; 6 — canal planned

The waters of the upper sections of the Danube deprived of    eir deposits, can no longer move a significant amount of alluvium neither at the Nagymaros nor at the Adony revervoir, one above the other below Budapest.

The planned Danube — Tisza Canal would pass through rather loose sediments. The movement of water flowing along and the backwash caused by the ships would lead to bank erosion and to considerable aggradation if it were not prevented artificially.

The Tisza transports only suspended load but this is a greater load than that of the Danube if we compare the capacity of both rivers. Nevertheless, one does not have to reckon with a more significant aggradation because the slower movement of water reduces channel erosion. The only areas where aggradation may be a problem is the section of the Tisza below the outlet of the Sajó and the Maros; both tributaries carry rich alluvia into the Tisza. The situation at the outlet of the Maros is further complicated by the construction of a dam in Yugoslavia near Nowi Becej (Újbecse).

A general consequence of the slowing down of water movement is that the changes in the river-bed will take a much longer time than they do at present.

2. *Changes in the seasons of navigation.* At present river traffic is considerably hindered by periodic lack of adequate conditions for navigation, e.g., very low water levels. The water reservoirs and the dams eliminate fords and thus intervals of no navigation will be limited to icy winter periods.

The breaking-up and drifting of ice in winter will start ealier behind the dams, similarly the freezing of the ice also unless it is artificially prevented. Thus, though the period of navigation is prolonged the ice may prove to be a problem in winter. Incidental icy floods can be controlled by the operation of sluice-gates at the dams and thus their danger and frequency can be limited. The more balanced water regime due mainly to the dams and channels accelerates river traffic upstream only, i.e., behind the dams it is a significant time factor. This is complemented by the night traffic in the smoother section, and the introduction of modern communication and navigation techniques. These improvements add up to nearly 40% extra navigation-time.

3. *Effects on water quality to be expected.* The occupational regrouping of the population and industrial development along the rivers, the use of chemicals in agriculture in the cultivation of the riverside areas led to the deterioration of the quality of the water. We must also add the pollution caused by water traffic. The construction of the transcontinental shipping routes means that the rivers in Hungary may now be termed to belong to the category of big lakes, where there is no self-purification by natural water movement, and with the increased traffic the danger of pollution becomes more imminent. Protection against pollution would not be sufficient even if all waste and used water that enters the river in Hungary is completely purified since Hungary occupies only one quarter of the total (titel) catchment area of Danube and cannot carry the burdens of the other three quarters of the catchment area. In this respect only effective international co-operation would be of help.

Sources of imminent danger of pollution in the Upper Danube section are the oil-products coming from abroad, the waste waters of Budapest entering before Adony, the  waste waters of the industrial plants and suburbs of Southern Pest, flowing into the Danube — Tisza Canal. Entering the Kiskőre Reservoir the waste waters of the Sajóvalley and Leninváros and above the Novi Becej Reservoir the waste waters of Szeged are discharged. It is a fundamental requirement that as  the channelling of the river progresses, plants for purifying

these waters should be built alongside so that the absence of reduced self-purifying effects should not cause irredeemable damages in the quality of water.

The further effective planned social intervention in the life of the Hungarian rivers will naturally have several other consequences. The soil water balance along the river side will be radically changed so will the present vegetational cover of the flood-plains as the artificial lake partly inundates these plains, and the dynamics of soil development are altered both within and outside the new embankments; local climatic changes are also to be expected near the reservoirs. At present, we merely refer to these expected changes as the future examples of the intensive present-day interventions in the life of rivers in Hungary.

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# POTENTIAL FOR CHANGE IN THE WATER CYCLE ON CULTIVATED SLOPES

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## 1. INTRODUCTION

### 1.1. SCOPE OF WORK

Land use is one of the important factors which differentiate both the quantitative and qualitative water cycle structures in the soil. The term land use refers to the spatial arrangement of both vegetation cover and the agricultural activities of man. The knowledge of relationships between soil water cycle and land use makes it possible to determine the impact of man on the water cycle and to control the soil water cycle by rational land use.

The above problem is discussed by taking as example the results of continuous measurements at Szymbark in the flysch Carpathians. The study area is situated on the boundary of two major relief types: the Carpathian Foothills and the Beskidy Mts. (Beskid Niski, L. Starkel, 1973). In the Foothill region, slopes consist of flysch series with prevailing shales on which loamy soils have developed. Slopes are occupied by cultivated land. The forested Beskidian slopes are mostly made up of flysch sandstone and have loamy soils with high frequencies of skeletal particles. Forests are still in their natural state there (J. Staszkiewicz, 1973).

### 1.2. NATURE OF THE WATER CYCLE ON FORESTED AND DEFORESTED SLOPES

Comparison of the water balance on forested and deforested slopes reveals the extent and trends of changes caused by the removal of forest cover in earlier centuries. It appears that the percentage share of infiltration in the open is similar to that under forest (Table 1) because of high rainfall interception by forest. Differences in the runoff processes are essential. The maximum intensity of surface runoff on a wooded slope is 50-times smaller than that

TABLE 1. Water balance in forest and in cultivated areas at Szymbark — percentage comparison

| Area | Precipitation | Interception, depression storage | Surface runoff | Infiltration |
|---|---|---|---|---|
| Forest | 100 | 20–25[a] | 0–5 | 70-80 |
| Cultivated areas | 100 | 5–20[a] | 5–20 | 60-90 |

[a] according to K. Dębski (1970)

TABLE 2. Maximum intensity of runoff expressed in 1/min · ha in forest and in cultivated areas at Szymbark (according to E. Gil)

| Area | Maximum intensity | |
|---|---|---|
| | overland flow | throughflow and interflow |
| Forest | 150 | 160 |
| Cultivated area | 8,250 | 190 |

on cultivated slopes (Table 2). The intensity of subsurface runoff in the 1 m slope mantle is smaller. This can be explained by the similarity of the deeper soil horizons under forest and in the open (B. Adamczyk and co-workers, 1973).

The above hydrological differences are only in part due to the influence of forest. It should be remembered that the forest cover has mostly been removed from areas useful for agriculture. Forest was left on slopes containing skeletal soils, unsuitable for cultivation. Thus, numerous environmental factors are responsible for the varied water cycle in woodland and in the open. Structure of the soil profile and lithology of bedrock are of major importance. Such are the varied natural conditions on the experimental slopes at Szymbark (Table 3). It may be assumed that the reforestation of the cultivated slopes would not be effective from the hydrological point of view.

TABLE 3. Natural conditions of the experimental slopes "Jelenia" and "IG PAN" at Szymbark

| Elements | "Jelenia" | "IG PAN" |
|---|---|---|
| Lithology | sandstones | shales/sandstones |
| Soil | skeletal silty-loam | silty loam |
|    total porosity in % of volume | 46.1–60.2 | 40.7–51.2 |
|    capillary porosity in % of volume | 36.8–53.4 | 33.3–42.5 |
|    infiltration in mm/min | 0.8–42.9 | 0.07–11.4 |
| Vegetation | Forest: *Dentario glandulosae Fagetum* | cropland/grassland |
| Slope profile | straight | straight |
| Slope and exposure | 19°, NE | 12°, SW |
| Altitude in m a.s.l. | 550–650 | 300–350 |
| Annual precipitation in mm (1969) | 715 | 670 |
| Mean annual min. and max. temperature in °C | 3.1–9.5[a] | 1.8–12.0[a] |

[a] according to B. Obrębska-Starklowa (1973)

### 1.3. NATURE OF THE EXPERIMENTAL SLOPES

The experimental slopes at Szymbark represent different natural conditions (Table 3). The slope "Jelenia" representative of the wooded Beskidian slopes is composed of the Magura sandstone series. It is situated in the lower mountain zone (*regiel dolny*). The "IG PAN" slope representative of the cultivated Foothill slopes is formed of shales and sandstones belonging to the *Inoceramus* strata. It was the aim of continuous measurements to find out the mechanism of change from precipitation to runoff. This phase in the water cycle takes

place on the slope. The measurements of each of the elements in the water cycle were made on the "IG PAN" slope. These included: precipitation, water infiltration and percolation, surface runoff (overland flow), subsurface runoff (troughflow and interflow), soil moisture content and oscillations of the ground-water level (J. Słupik, 1973).

## 2. THE HYDROLOGICAL ROLE OF LAND UTILIZATION

### 2.1. THE PROBLEM

The utilization of cultivated areas varies with the seasons of the year. At the same time weather is changing. Knowledge of the hydrological role of land use involves analysis of the water cycle during different weather. The results of measurement at Szymbark demonstrated that different types of weather — each characterized by a distinct set of hydrological processes — can be distinguished. Downpours of short duration, long-lasting continuous rains and snowmelts are typified by the increased activity of runoff processes. During the other rains either infiltration or interception is predominant. In the rainless periods of the summer season (from May to October) evapotranspiration prevails. During the frosty periods hydrological processes disappear. The causative relationships between soil water cycle and land use vary with the weather (E. Gil and J. Słupik, 1972a, 1972b; J. Słupik, 1972, 1973, 1974; J. Słupik and E. Gil 1974).

### 2.2. NATURE OF THE SOIL WATER CYCLE VARYING WITH THE WEATHER

During the summer drought dessication of the soil takes place due to the intense evapotranspiration. In spite of the warm weather (daily mean air temperature of 17.2 °C, maximal air temperature of 31 °C, maximal temperature of ground surface of 51 °C), after 20 rainless days some 80 mm of water available for plants have been recorded in the 0.5 m soil layer (Fig. 1). The level of cultural plants was very good then. The conclusion is that the loamy soils on the flysch slopes have water in excess of that needed by plants, even at the height of the growing season. There exist possibilities of increasing water consumption rates in the process of evapotranspiration.

In the rainy periods and during thaws, the role of land utilisation is reduced to that of controlling the quantitative proportions of surface retention,
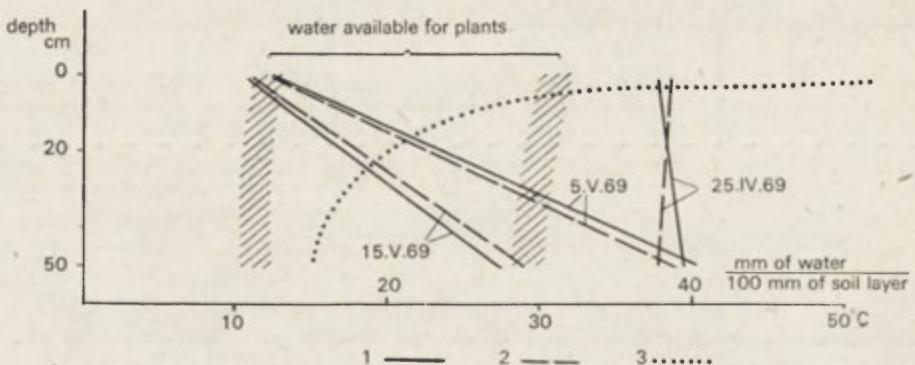


Fig. 1. Changes in soil moisture on the "IG PAN" slope at Szymbark during drought
1 — soil moisture in the upper part of slope, 2 — soil moisture in the lower part of slope, 3 — maximum soil temperature

surface runoff and infiltration. As the depth increases the influence of plants is reduced. The rates of both percolation and subsurface runoff are similar under various cultural plants (J. Słupik, 1974). These rates are closely related to the nature of the ground. For this reason, we can concentrate our attention on the variety of overland flow.

During short downpours both volume and intensity of surface runoff is controlled by the vegetation cover (Table 4). As a result, on the grass-covered slope water retention in the soil was 86% of the total precipitation and that on the potato field was 55%. This great variation in overland flow can be explained by the well known principles of runoff hydraulics. According to L. Schiff (1951), as the vegetation cover density increases, the ground roughness will be increased. This means that the surface retention necessary to initiate water flow in grassland must constitute a thicker layer of water, whereas smaller quantities of excess rainwater are quite sufficient to initiate runoff on the bare soils. During rainfall with an intensity of 1.74 mm per miute on the grass-covered slope surface runoff commenced afer 34 minutes since beginning of rainfall. Thus, it may happen that when downpours are short no surface runoff will occur neither on grass-covered slopes nor on corn fields. With the same surface retention, the velocity of overland flow-declines as density of vegetation cover increases (L. Schiff, 1951): on the grass--covered slopes the velocity of water flow is 2 cm/s, on the bare soil it reaches 1 m/s (K. Figuła, 1960). Compared to grass and corn, the velocity of surface runoff is much greater under root crops. This is the cause of increased runoff intensities (Table 4).

TABLE 4. Surface runoff on the "IG PAN" slope during short storm rainfall

| Elements | grass | potatoes |
|---|---|---|
| Precipitation total in mm | 43.2 | 43.2 |
| Maximum rain intensity in mm/min | 1.74 | 1.74 |
| Rate of surface runoff in mm | 0.0 | 10.2 |
| Maximum runoff intensity in l/min · ha | 17 | 3,400 |

During downpours land utilization permits both volume and velocity of overland flow to be controlled directly. The maximum difference in runoff rates is equivalent to a layer of water 7.4–10.2 mm thick during downpours above 40 mm in 30–40 minutes. In Poland such downpours are rare (J. Lambor, 1971). This 10 mm difference gives the upper limiting value of the influence of vegetation. This value applies to the cultivated Carpathian slopes containing loamy soils. Continuous rains (lasting a few days) of high precipitation totals may be above 100 mm (T. Nedzwiedz, 1972). The amount of falls exceeds the soil water capacity leading either to surface or subsurface runoff of excess water. The magnitude of both types of runoff depends on the proportions of precipitation totals and capillary water capacity of the ground. The runoff volume is determined by the structure of the ground and not by the utilization of land (J. Słupik, 1973). Similar rate of surface runoff has been recorded in all cultivated areas (Table 5). The influence of the vegetation cover is manifested only in the intensity of overland flow. The latter will be reduced as the

density of the plant cover is increased (Table 5). Thus, possible changes in the water cycle during continuous rain should be limited to the control of runoff velocity.

The remaining rain types include: (a) rains with totals not surpassing the actual soil water reserve, and (b) rains with intensities not exceeding the rate of water infiltration. Those rains may cause surface runoff only in furrows and on field- and forest roads. On the fields such rains are favourable for the water storage in the soil. Overland flow and percolation are minimal then and subsurface runoff does not occur (J. Słupik, 1973, 1974).

TABLE 5. Surface runoff on the "IG PAN" slope during continuous rain of 4 days' duration

| Elements | grass | potatoes |
|---|---|---|
| Precipitation total in mm | 167.2 | 167.2 |
| Amount of surface runoff in mm | 25.3 | 23.4 |
| Runoff coefficient in % | 15.1 | 14.0 |
| Maximum intensity of flow in l/min · ha | 765 | 848 |

The flow of water on the slopes is accelerated and concentrated by field- and forest roads, and by furrows as well (E. Figuła, 1960). These are characterized by low permeabilities and the absence of vegetation, and they drain water from the soil layer. Measurement at Szymbark revealed that the volumes of water using a furrow 130 m long and draining a field of 130 × 13 m are similar (Photo 1). The water flow velocity in a furrow was exceeded some ten-



Photo 1. Measurement of overland flow in a furrow on the "IG PAN" slope

Photo 2. Furrows and field roads make a very high drainage density on slopes
(surroundings of Szymbark)

fold (above 1 m/s) (K. Figula, 1960). The density of both furrows and field roads
at Szymbark is about 50 km/km² (Photo 2). For this reason I am of the opinion
that furrows, field- and forest roads are the main source area of water supplied
from the slopes into the stream channels during high discharges. The high velo-
city of water draining the network of furrows and roads determines essentially
the peak flows in the small Carpathian catchments. During downpours, furrows
and roads also add to the volume of water flowing downhill into the stream
channels. The conclusion is that by reducing the number of furrows and roads
runoff velocity can be much reduced. The same applies to the volume of over-
land flow that takes place on the slopes during downpours.

During thaws (snowmelts) the soil moisture content is high. Most frequently
it approximates to the full soil water capacity (J. Słupik, 1974). Thus, condi-
tions are similar to those prevailing during continuous rain. The magnitude of
overland flow is determined by the state of the ground.

In the winter season (November–March) the major role is played by ground
temperatures (Table 6). The influence of land use is that of differentiating

TABLE 6.  Surface runoff on the "IG PAN" slope during snowmelts in different soil conditions

| Elements | frozen soil | | not frozen soil | |
|---|---|---|---|---|
| | grass-covered | ploughed | grass-covered | ploughed |
| Amount of surface runoff in mm | 27.5 | 21.5 | 3.8 | 0.1 |
| Runoff coefficient in % | 77.9 | 60.7 | 5.0 | 0.1 |
| Max. intensity of flow in l/min · ha | 195 | 170 | 35 | 12 |

the runoff velocity. Some changes in the runoff volume may be estimated by increasing the surface retention of the ploughed fields. Compared to a grass-covered slope, the decrease in runoff volume on a ploughed field is distinct and independent of the then prevailing state of the ground (Table 6). However, variation in overland flow volume is compensated by higher subsurface runoff rates on the ploughed field. Throughflow occurs chiefly in the arable layer (J. Słupik, 1972b; E. Gil).

The possibility of changes in the water cycle is limited to the control of flow velocity. Lower velocities have been observed on the ploughed fields (the furrows due to ploughing are ignored). For this reason, the hydrologic effects may be greatest, if the number of both furrows and field roads had been reduced. This method is likely to decrease runoff velocities during snowmelts and in rainy periods.

## 3. CONCLUSIONS

Both type and method of land cultivation has a direct bearing on the runoff velocity and a partial influence upon the overland flow volume. Runoff conditions may be improved in two ways: by increasing runoff volume and accelerating the downhill flow, or reducing both the volume and velocity of overland flow. On the Carpathian slopes, the decreased runoff velocites will increase periodically the water retention in the soil. It also will diminish the rates of soil erosion. This will lead to excessive soil moisture being disadvantageous for two reasons: firstly, the growth of plants will be limited; secondly, conditions will be favourable for landslide initiation. Agricultural production necessitates increase (or acceleration) of the water flow during wet periods, when runoff volume and velocity should be reduced in order to protect the soil from erosion. A complex discussion of changes needed in the water cycle on the flysch Carpathian slopes is contained in another paper.

The effects of changes in the water cycle structure that have been caused by the utlization of land do not pertain only to slopes. As the runoff velocities on the slopes are decreased the peak flows in small catchments are reduced. Thus the danger of both flooding and channel erosion will be reduced in areas extending above the dams. The control of water flow velocities on the slopes is the only way to reduce the effects of floods in the small catchments. As far as larger drainage basins are concerned the control of the downhill flow of water is less effective. Floods are produced only by continuous rains there, when the runoff volume does not depend upon land utlization. The peak flows are governed by the different lengths of time the water needs to come from the small catchments (J. Lambor, 1971). Reservoir construction is the only way to diminish the effects of floods on the Carpathian tributaries to the Vistula river.

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# THE SILTING PROCESSES OF THE ARTIFICIAL WATER RESERVOIRS IN THE POLISH LOWLAND

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In Poland as well as in many other countries one of the fundamental demands for further economic progress is effective safeguarding of water resources of suitable quality and quantity to cover present and future requirements of population, agriculture and industry.

In view of this necessity it is planned to construct in Poland a number of additional reservoirs, many of these — and mainly the largest among them — are going to be built on rivers in Poland's Lowland. In the design of such reservoirs an essential factor is due calculation of how long they will be of use because this consideration of the economic aspect of building the reservoirs and of the nature and extent of their further use, involves also a wide range of later auxiliary investments. In the desigh plans this sort of prognosis is made by different, mostly indirect, methods and, most often, they are based on calculations of the intensity of surface washdown (denudation) and erosion, and of bank abrasion in river valleys lying within the range of the future catchments area.

However, from numerous instances witnessed during recent decades and in many countries of the World — especially in the USA and the Soviet Union — it is well known that this sort of preliminary theoretical calculation of the intensity of possible silting of new water reservoirs has proved to be fallacious in many instances. It is a fact that artificial reservoirs whose period of usefulness had been believed to last hundreds of years or, at any rate, long periods, have been completely silted up within a dozen years or less, resulting in heavy economic losses.

This is why work on improving methods for preparing forecasts of the life of new reservoirs continues. Among other things, these efforts are to be supported by investigations into the rates at which existing water reservoirs are being silted up, because any observations of the results obtained in this way may considerably improve the accuracy of such preliminary, rather theoretical forecasts of the life of reservoirs which are to be made under conditions resembling those of present-day physico-geographical, and particularly, of locally determined geological-lithological and hydrographic conditions.

Obviously, a detailed description of all these investigations would far exceed the framework of the present study. Hence the author decided to give merely a brief survey of the method so far applied in Poland in this sort of examination of the rates at which existing reservoirs are being silted up, and of the assumptions used in anticipating rates of silting up of such newly constructed reservoirs.

Most often this rate is estimated from the intensity of denudation, i.e. from processes of surface soilwash (Reniger, 1959) observed within the drainage area in question and expressed by what Dębski (1959) called the "index of denudation", in values of t/km²/y. Variations on this method are direct measurements of the material eroded and carried off, expressed in g/m³ of water for material floating in or dragged along a river bottom, or in tons or m³/y, when this material is brought into the reservoir from the catchment area (Brański, 1966, 1968; Cyberski, 1969; Mikulski and Chomiak, 1963; Wiśniewski, 1969). In both instances mentioned above there must also be calculated the "reservoir capacity of retaining the material supplied", expressed in a percentage of the total quantity of material supplied by the river; usually this figure varies widely, from 40% to 95% (Wiśniewski, 1966, 1970 a,b).

It should also be mentioned that in some cases periodic measurements were made of the changing depth of the reservoirs caused by silting. Such measurements were made either by classical methods at a great number of points, or by continuous so-called echo-sounding along definite fixed cross-sections (Basiński, 1964 a, b; Onoszko, 1962, 1964; Wiśniewski, 1963). The thickness of the bottom deposits used to be determined either from knowing original depths at points of particular cross-sections, or from measurements repeated every few years. In both cases the amount of silting used to be recorded in millions of m³/y, or in figures indicating the annual increase or loss in thickness of the previously determined bottom deposits (Wiśniewski, 1970 a, b).

However, the results obtained from all the above methods proved to be rather inaccurate, especially when the "coefficient of denudation" has been chosen very arbitrarily. The results were only a little more accurate by measuring the material floating in or dragged along by the river ,mainly due to difficulties in measuring at all during flood periods). Nor can it be considered any more reliable to give data stating the capacity of a reservoir, i.e. how much of the impounded material it can retain.

As well as this, and usually omitted in all these calculations was the autochthonic, mainly organic material which accumulates in the bottom of storage reservoirs in consequence of biological processes; yet the share of this material in the silting up of some reservoirs can be considerable.

When the silting up of storage reservoirs is measured by checking their reduced depths the results may also be rather unreliable, no matter whether they were obtained by the classical method or by echo-sounding. The reason is, that very often — down to some 30 or 50 cm depth — the top layer of the bottom deposits, especially when containing larger quantities of organic material, is a soft, even semiliquid mass. Here the basic difficulty, so far practically unsolved, lies in establishing the true depth revealed by echo-sounding, or the true depth to which the weighing element of a classical sounding device penetrates the soft top layer of the deposit. Inaccuracy of the apparatus used may also have to be taken into account (in the case of echo-sounding) and errors may be caused by wave action.

Considering all the difficulties involved, the author of the present report tried to determine by means of core sampling the rates at which reservoirs lose their retentiveness followed by measurements of solid cores extracted from the bottom deposits. They illustrated in vertical columns the structures of the bottom deposits in a downward direction, from water-sediment surface to the bedrock (say, to a submerged meadow). In order to obtain and extract this sort of solid core from the bottom deposits, the author applied a core sampler of his own design (Więckowski, 1970). From 1958 onwards this device was used successfully in Poland in comprehensive investigations of the bottom deposits

of many natural lakes and, moreover, in determining the rates at which these lakes are being silted up (K. Więckowski, 1968).

In wintertime the job of depth sampling is done from the ice surface, at points accurately marked along geodetically marked series of cross-sections or at points of a uniform network of squares. During the summer, sampling is done from a floating platform (of the catamaran type), and the cross-sections are laid down from marking poles set up on opposite lake banks. The distances between particular sampling points sounding are either established by optical range-finders, by triangular interaction, or by using a measuring tape with one end attached to the bank.

The method of determining the rate of silting up, resulting from direct thickness measurements of bottom deposits as has been described in detail before, has also been applied at two artificial water reservoirs situated in the Polish Lowland: at Zegrze on the Narew and at Włocławek on the Vistula rivers.

The Zegrze Reservoir (*Zbiornik Zegrzyński*), built in 1962, has a surface area of 33 km² and a lenght of approximately 18 km. This reservoir may be divided into 3 parts differing in shape and in hydrodynamic regime as follows: a lower, relatively narrow (about 600–800 m) and almost straight part some 8 km long, a middle part about 5 km long and up to 3 km wide forming what is called the deep basin, and an upper part, very narrow and 4 km long.

During our field studies carried out all over the area of this reservoir, corings were made along 20 transverse sections (at 1 km intervals)) to determine the thickness of the bottom deposits in 360 points and to collect from 100 points samples to be analyzed in the laboratory.

Simultaneously observations were made for defining the hydrodynamical regime in particular parts and zones of the reservoir, depending on the shape of the reservoir and the relief of its bottom. Most important in this case was the determination of the different velocities of the water, because they effect the type of bottom deposits laid down and the rate at which these deposits accumulate.

It appeared that not only in the former channel of the Narew river but also outside the channel in the areas which are now inundated, the hydrodynamical regime of water resembles much more that of a river than a lake. Evidence for this is the lack of vertical thermal stratification of water layers so characteristic of most lakes; also characteristic are the periods in which a complete water exchange in the reservoir takes place. It was found that, even when river outflow had dropped its next to lowest values, a complete renewal of water in the reservoir averaged 14 to 16 days, whereas for flow volumes approaching mean long term values a full exchange takes place every 4 to 6 days; during flood periods this even happens every 12 to 24 hours. Hence the Zegrze Reservoir can by no means be classiffed as one marked by a "delayed water exchange" — this being one of the main features characterizing the hydrodynamical regime of lakes, including drainage lakes.

Our reasoning is also confirmed by the results of hydrobiological examinations (Dojlido et al., 1967), from which their authors conclude that "from the viewpoint of both their chemical composition and their biocenosis the waters of the rivers Bug nad Narew revealed but minor changes being after ponded up; hence it seems that ostensibly the lacustrine features only faintly observed in the Zegrze Reservoir are typical of this kind of lowland storage reservoir. It should be added here that these "faintly observed lacustrine features" were identified by the authors merely in the area of the wide "deep"

part of the reservoirs, conspicuous by the greatest stability of its water masses.

Investigations have demonstrated that, due to the rapid flow within the former Narew channel, some 150 to 300 m wide and extending nearest the high right-hand lake shore, no material brought into the lake in suspension is being deposited; and that there is merely accumulation of some fine- and very fine-grained sand dragged in along the channel bottom.

On the other hand, all over the wide area that became submerged after pondage, deposits were being laid down consisting of dark green or, mostly, dark brown clayey mud with a considerable admixture of organic detritus, for the most part remmants of flora and fauna growing within the reservoirs. However, this content of organic substances averaging some $10^0/0$ in volume shows spatially wide differences, from $1-2^0/0$ to $20^0/0$; similar discrepancies lacking any sort of uniformity show also the degree of sand admixture these deposits contain. It seems clear what is to blame: all over the lake surface sand is being scooped up and dredged most of the time; it is then transferred to the shore where it is used for smoothing beach surfaces, levelling bank lines and filling in unwanted depressions. All this work is done on a fairly large scale, so that now this continuous removal and transfer of material from the lake bottom leads here and there to widespread areas of excavations and uneven heaps of material. Because this practice causes constant relief changes in the lake bottom, in sum total these endeavours greatly obstruct a clear vision of the spatial differences developing in the intensity of accumulation and in the very character of the bottom deposits.

Resuming our description of the bottom deposits it should be added that they contain a bare 3 to $5^0/0$ $CaCO_3$, due mainly to the plentiful occurrence of broken shells of *Dreisensia Polimorpha* in the reservoir. The consistency of the deposits changes gradually, from semiliquid in the top to compact in the bottom layers; the specific gravity, correspondingly changes from 1.1 to 1.8 $g/cm^3$. In the size classification of the mineral part, fine-grained sand and silt fractions predominate while the share of clayey fractions is small, only from 2 to $5^0/0$.

By reason of the large number of samplings made it was possible, after all, in spite of the above described difficulties, to determine fairly accurately the differences in how much bottom deposits have accumulated in particular parts and zones of the reservoir. It was found that bottom accumulation of the deposits proceeds slowest in the lower part of the reservoir, with their thickness ranging from 0 to 20 cm, and 10 cm on the average. These deposits are dark brown mud with a low content of organic material, but are fairly strongly mixed with sand.

Sedimentation is more prounced in the middle part of the reservoir — mainly due to much slower water flow within this widest part of the reservoir. Here the deposits are from 0 to 40 cm thick, averaging 15 cm. These deposits resemble those mentioned before, but contain more organic substances and usually less sand.

Finally, in the upper part of the reservoir the deposits are from 10 to 60 cm thick, again averaging 15 cm; they are much diversified with regard to the organic substances content and sand admixture. In stratification thin mud layers often alternate here with beds of fine- and mediumgrained sands. This diversity of the deposits is caused by the wide varieties occurring here in flow rate and flow volume during periods of low water and of floods.

An analysis of all our measurements indicates that, on the average, the thickness of the bottom deposits grows annually 0.5 cm in the lower part of

the basin and 1.0 cm in the middle and the upper part. In view of the fact that the mean depth of the particular parts of the basin differs, the Zegrze Reservoir is bound to lose its retentive value by degrees. Realizing that due to natural processes the intial thickness of the bottom deposits is going to grow sons it was impossible to take into account phenomena and processes which deposits the reservoir will have lost its usefulness and its faculty of retaining surplus water, calculations reveal that for the lower part of the reservoir the total silting up is going to occur after some 600 to 800 years, for the middle part after some 450 to 550 years, and after 300 to 400 years for the upper part of the reservoir.

However, this estimate is merely an approximation, because for other reasons it was impossible to take into account phenomena and processes which in future may essentially change, periodically or continuously, the conditions and the rate of silting.

The Włocławek Reservoir (70 km²) extends between Włocławek and Płock, forming a fairly narrow (only 1–2 km wide) and practically straight band of water storage. The eastern bank of this reservoir is almost identical with the former Vistula bank, while the left-hand (western) bank consists alternatively of sections of an earth dam piled up on the flood or overflood terraces, and of fragments of the natural fairly high margin of the Vistula valley.

The nature and scope of studies concerned with the reservoir site — covering only the lower part of the basin, up to some 20 km in upstream direction — resemble what was done in the Zegrze Reservoir. Along 10 transverse cross-sections 160 soundings were made, combined with extraction of cores of the bottom deposits in order to measure the thicknesses of the deposits and to collect samples for laboratory examinations. Also studied was the flow regime within the basin. It appeared that this regime resembles very much what has been determined for the Zegrze Reservoir, both as regards differences in flow velocity in the transverse sections and as regards a complete water exchange under particular conditions of unit flow during the year.

Our investigations indicated that within the reservoir the bottom deposits are mostly laid down in a fortuitous manner. Even so, the differences in the rate of deposit accumulation show some regularities, depending on present-day flow conditions as well as on the original relief of the bottom of the reservoir.

It came to light, that next to the high right-hand bank which is suffering heavy destruction by abrasion causing huge landslides, in a zone 30 to 50 m wide new deposits were constantly being accumulated from what had been carried off from destroyed banks. The thickness of these deposits may be as much as 70 cm and its average thickness some 30 do 40 cm. Nearest the bank this material consists first of medium- and fine-grained dark sands and, farther off, of slightly clayey dark silts; this material contains a bare 1 to 2% of organic substances; its specific gravity is 1.6 to 1.8 g/cm³.

However, the process of demolishing the high right bank is going to come to an end fairly soon — as soon as a new profile of equilibrium has been formed in the submerged part of the inclined bank slope and a new beach strip develops. While this process is under way, deposition of washed-down bank material in this basin zone is bound to grow steadily less, and finally to lose its influence upon the nature and the rate of basin silting.

In the remaining part of the zone occupied by the former Vistula channel, practically no deposition of a clayey, nor even a silty fraction is taking place, apart from filling local deeper depressions. The reason is, that compared with other areas submerged after river ponding, the former Vistula channel has a fairly well smoothed bottom and profits therefore from much better flow

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conditions. Hence this former river channel continues to be a zone of more rapid flow with velocities much higher then in the remaining zones, and up to 80% of all water passing through the reservoir is moving in this zone. Under flow conditions like these, only a slight accumulation of mainly medium grained sands can be expected to take place here.

Dark, greenish-brown clayey silts with a considerable (5-10%) content of organic material and a specific gravity of 1.1 to 1.5 g/cm³ are deposited in great quantities, yet at a fairly varying rate (from 0 – 30 cm, and some 10 cm on the average) mostly in the zone of the former flood terrace where these silts fill, first of all, most of the previously depressed parts of the terraces.

Finally, it is worth mentioning that in the shallow water covering a strip some 200 m wide or more along the western bank of the basin, wave action contributes to levelling of the initially uneven sandy bottom. The thickness of the fine grained, sometimes clayey, depositis indisputably determined at paces where on submerged turf bottoms exact measurements were possible, proved to be from 6 to 25 cm; these deposits vary (from 1 to 10%) in the amount of organic material they contain. Also divergent is their specific gravity, ranging from 1.2 to 1.8 g/cm³. Still, on the whole, it seems that during today's early stage of basin evolution, the effects of erosion and accumulation are cancelling each other out.

To sum up, we see from our investigations and observations that the features of sedimentation and the intensity of deposition reveal wide differences in both the transverse sections and in the longitudinal profile of the reservoir. As was said before, processes of abrasion occur at a high rate on the high northern bank, of bottom erosion, and of redeposition of deposits, especially in the wide shallow-water zone extending along the southerm bank of the reservoir. And these facts explain why, in the size frequency of the mineral part of the deposits from all zones of the basin, the fine grained and silty fractions markedly predominate.

During the present-day initial stage of reservoir formation all the processes and phenomena reported above are taking place with particular intensity. This is caused by the differences in flow velocities in the particular zones and parts of the reservoir due to the complex relief of its recently submerged bottom zone and to the action of waves, so particularly effective where the water is shallow.

But, gradually, the result of all these processes leads to a step-by-step stabilization of a new bank line, to the formation of a new profile of the submerged scarp in the slopes of the reservoir bowl, and to a general levelling of the reservoir bottom. Only the channel zone of the previous Vistula flow is going to maintain its modified but still smooth profile. From what has been said so far about the complex character of the reservoir and the differences observed within it, and about the gradual changes anticipated due to processes of sedimentation and accumulation, it can readily be seen that at the present stage it would be difficult to define values of the probable annual growth of the bottom deposits with regard to the whole bottom surface of the reservoir and on this basis to estimate the duration of the expected useful life of the reservoir. Our measurements indicate, that the deposits may grow in height along the order of 0.5 to 1.5 cm per year.

Adopting preliminary assumptions similar to those applied for the Zegrze Reservoir one may presuppose in a first approximate estimate the useful life of the Włocławek Reservoir to be 400 to 600 years; should a neighbouring basin be constructed near Wyszogród, at least 50% would have to be added to the life of the Włocławek Reservoir.

It is impossible to supply a more detailed forecast until the next series of measurements is made, after a period of at least some 10 to 15 years. By this time all processes transforming the banks and the bottom of the reservoir should be much mitigated. At present, only a few years since the Vistula has been ponded at Włocławek, all these changes are taking place rapidly and therefore they very much obscure the image of the true rate at which the reservoir is being filled with deposits.

RECAPITULATION

As has been demonstrated in the first chapter, the methods so far in use for appraising the rate of filling storage reservoirs with deposits and estimating their useful life cannot be expected to yield satisfactory results. The reason is, that on the one hand these methods are based on most unreliable source data and, on the other, that they fail to take into account phenomena and processes, continuous or periodical, which may often cause essential changes in local conditions of sedimentation and in the rate of blocking up the reservoirs — changes either liable to speed up or to delay these processes.

Among agents delaying basin silting should be mentioned what is called "self-purging", "settling" of the deposits during periods when reservoirs are drained, or settling them due to wind-actuated waves. On the other hand, one factor accelerating silting is a vigorous growth of organic life in the basin and in the rivers feeding the reservoirs.

In the Zegrze and the Włocławek Reservoirs "self-purging" occurs during flood periods in the Narew-Bug valley and the Vistula valley. When the sluicegates are fully open, both these reservoirs turn into rapid-flow rivers (at 1 to 2 m/s), and this causes much of the deposits earlier laid down to be swept away. Admittedly a high-water flow also brings into the reservoir a greater amount of material; yet, apart from back-water zones, removal of bottom deposits during flood periods definitely surpasses deposition of newly brought-in material.

Periodical drainage of reservoirs leads to an extension of their useful life because, when a reservoir has run dry for a sufficiently long time, say several months, all over the exposed surface a definite "settling" of the deposits takes place, in consequence not only of the rapid decomposition of the organic substances the deposits contain, but also due to dehydration and desiccation. The effect is, that the thickness of the deposit may be reduced 30 to 50% or more; most often this is an irreversible process, meaning that upon the reservoir being filled with water the deposits are not going to „swell" back to their original volume. This observation was confirmed by studies made in the periodically drained Pilichowice, Leśna and Złotniki Reservoirs (T. Stokłosa, 1960; A. Jahn, 1968), as well as by the results of experiments made on deposits taken from the Włocławek and the Zegrze Reservoirs.

The effect of wind-actuated waves upon the reduction of silting processes can only be observed in fairly shallow reservoirs and in those parts of deeper basins where water movement caused by waves extends down to the top surface of the deposits. Water mixing, often also stirring of the uppermost semiliquid layer of the deposits, increases oxydation of the deposits and, in this way, leads to a more rapid and a more thorough decomposition of the organic material they contain. Moreover, this water movement, causing washing away of the upper deposits and converting them into a layer of suspended matter, will often cause part of the stirred-up deposits to be carried off beyond the reser-

voirs. Finally let it be understood, that a strong wave action, continuously shifting from place to place the sands and gravels spread over the bottom, effectively counteracts the growth of aquatic vegetation, both of submerged plants and of the "hard-stem" reeds. Proof of this also is the lack of aqueous vegetation in the windward parts of the bank zone of many lakes — in spite of the fact that here extensive shallow water zones occur.

In the two reservoirs under discussion, extensive zones of shallow water fringe these kinds of "windward" southern lake banks. With these parts of the reservoirs gradually becoming more shallow, the favourable effect of wave action may be expected to continue and increase; afterwards it would seem that, after arriving at some critical value (say about 1 m depth), further silting of the shallow lake zone may cease altogether.

On the other hand, biological life thriving in the reservoirs and the rivers feeding the reservoirs is apt to speed up the rate of reservoir silting. Even now, as mentioned before, products of lifeless flora and fauna constitute some $10\%$ of the deposits. Yet one must anticipate that in future, due to man's economic activities, the eutrophy of open waters, rapidly occurring almost everywhere is going to stimulate biological life in our two reservoirs also and, in this way, suitably to increase the amount of organic substances in the deposits. Most harmful here is the growth of both "hard-stem" and submerged vegetation, i.e. the formation of what is called "submerged meadows". This process is known to cause large quantities of plant remnants to be deposited on lake bottoms and to "smother" water motion, so that most of the material suspended in the water is going to drop to the bottom.

Hence, unless effective and inexpensive methods of counteracting plant growth are invented, our estimates of the useful life of shallow reservoirs similar to those at Zegrze and Włocławek, based solely upon their rate of silting in their initial stages of formation, may prove much too optimistic.

To sum up, our investigations reveal that the method of estimating the rate of reservoir silting based on direct measurements of the thicknesses of the deposits during the reservoir life yields auspicuous results. Its disadvantage is, that extraction of cores of deposits from a great number of points demands much time and effort; yet it is indispensable for obtaining reliable mean walues for the rate at which a given reservoir or parst of it are silted up. A further drawback may at times be the difficulty of establishing the boundary between the original lake bottom and the deposits — especially within previous river channels, in the zone where back-currents occur.

It is essential to remember that for reservoirs situated in the lowland reliable results can only be obtained from investigations made some 20 to 30 years after the reservoirs were constructed. This period of time is required to let processes of bank abrasion, of the formation of new balanced bank profiles in the submerged parts of the reservoir slopes, and of smoothing initial bottom depressions subside suffciently so that they do not obscure the image of real accumulation of deposits and of reservoir silting — as is the case in the initial period of their existence.

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# LANDSCAPE FACTORS MODIFIED BY AGRICULTURAL ACTIVITY

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1. The title of our paper suggests a very broad theme. It is well known that in the course of social development, mankind has extended its agricultural activity over large areas in order to meet the demand for more food and, by doing this, has significantly transformed the natural environment. At the same time, man has altered the progress of natural processes preceding human impact.

In our short paper we obviously cannot undertake even a roughly outlined survey of this group of problems, and neither do we see it as our task to discuss general theories. Instead we briefly analyse the changes that take place in a selected model area, the alteration of the natural processes as a result of agricultural production. Our aim is to determine the possible effects of further intervention.

By selecting the model area from among about 15 representative agricultural areas examined with the help of L. Góczán and J. Szilárd, we have decided to discuss the following area because it is representative of extensive areas owing to its geographical location in Hungary and its morphological characteristics.

The model area represents high and low flood-plain surfaces lying along the Danube, south of the capital, on the Csepel island (Fig. 1). As a result of detailed investigations we were able to reconstruct the effect of flood control and river regulation in the area, water management being regarded as an anthropogenic activity. It was in the light of this latter precondition that the effects of agricultural activity on the natural processes were evaluated. However, there was another reason for our choice of a flood-plain model area as the theme of our paper and this is the fact that such areas are common in Poland and thus an exchange of views and experiments may be possible.

2. Apart from some terrace islands originating at the end of the Upper Pleistocene (Il/a), which were flood-free in historical times and remained so even during the catastrophic flood of 1838 (Fig. 2) and therefore attracted settlements, the difference between the high flood plain and low flood plain of the Danube is generally only 5 meters (Fig. 1). Danube gravel is the homogeneous alluvial material. On the terrace islands it is overlain by wind-blown fluviatile sand, on the flood-plains by fluviatile sand, and to a smaller extent by silt and clay. On the surface loess-silt is the characteristic sediment. This latter is a characteristic soil-forming rock along the Danube; it is a typical flood-plain sediment (Fig. 3).

3. Before the regulation of the Danube and preceding the time when flood-control measures were introduced in the 19th century, the Danube covered the island with a network of channels, the majority of which were under
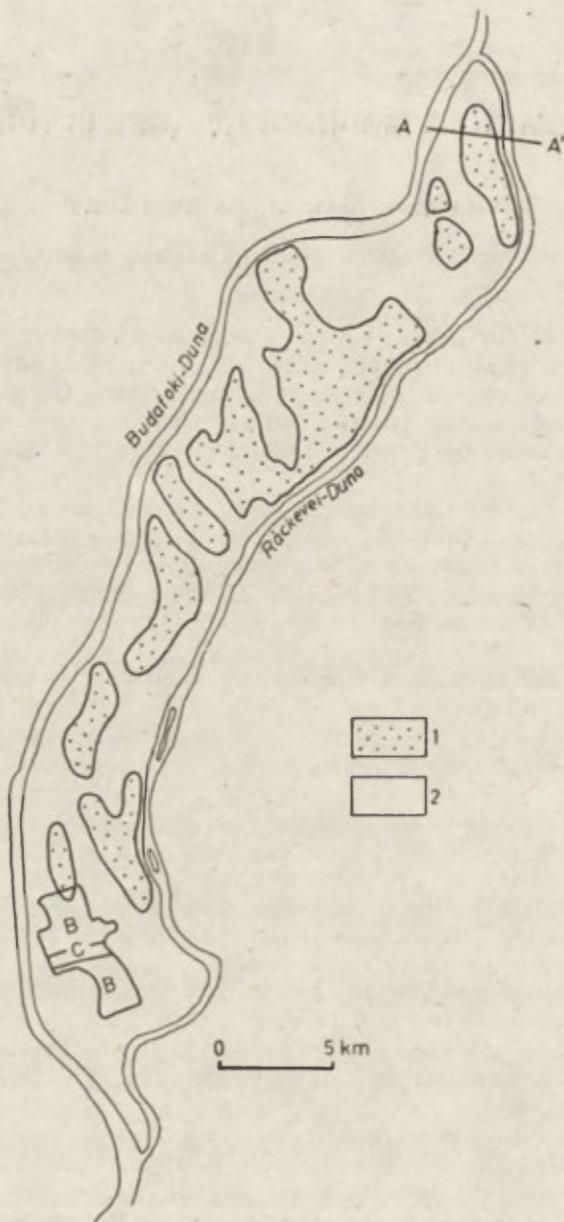
Fig. 1. Pleistocene and Holocene surfaces on the Csepel island, in the environs of our selected model area

1 — the II/IIa terrace of the Danube of late Pleistocene age covered with sand dunes; 2 — low and high flood-plain levels: the latter is characterized by a dense network of infilled abandoned channels (filled in by 1 or 2 m thick alluvium). See Figure 4 which is on a larger scale. A–A' — profile shown on Figure 3; B — model area shown on Figure 5; C — site of the geomorphological map shown on Figure 4
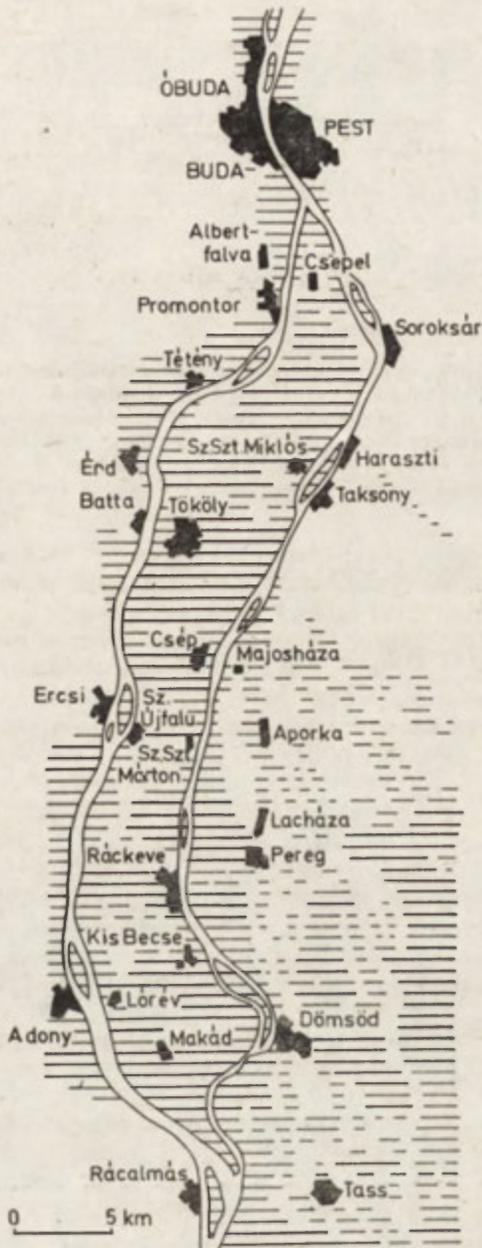
Fig. 2. Areas inundated during the flood of 1838 (horizontal shading) on the Csepel island.
Taken from the book *Pest-budai arviz 1828-ban* (The 1838 flood in Pest-Buda)

water only during floods (Fig. 4). This is especially typical of the southern part of the island, whose southward extension was due to point bar formation.

The natural mechanism of the river was thoroughly altered by the regulations. Prior to the regulation, the river could spread over vast areas during floods and the maximum flood-water level was lower than it is today: it sel-

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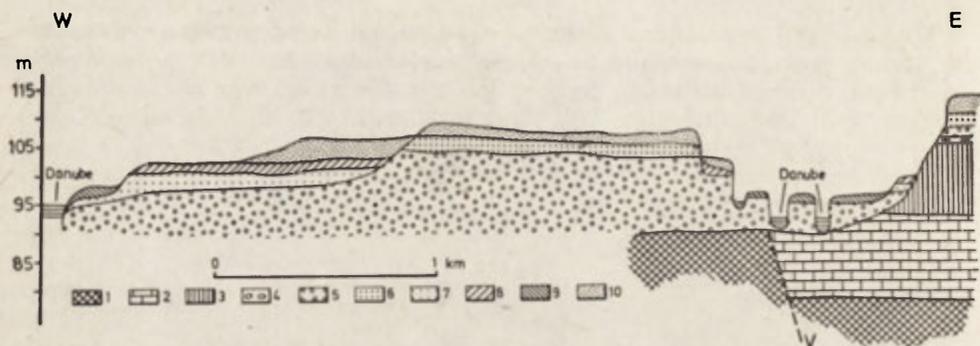


Fig. 3. Profile of the area from the Danube arm at Budafok to the brick-works at
Gubacs constructed by S. Marosi

1 — Mediterranean layers; 2 — Sarmatian limestone; 3 — Pannonian sediments; 4 — Pleistocene
debris-gravel cone; 5 — Upper Pleistocene gravel; 6 — Upper Pleistocene fluviatile sand; 7 —
Early Holocene fluviatile sand; 8 — Early Holocene calcareous mud (loess-mud); 9 — Late
Holocene calcareous mud (loess-mud); 10 — blown sand; V — fault

dom inundated the upper flood-plains. As a result of this, soil formation could
go on undisturbed until it became a stepp (chernozem) soil. On these upper
flood-plains, since inundation seldom occurred, it scarcely resulted in the accu-
mulation of sediments (shallow water); they only altered the dynamics of cher-
nozem soil formation towards a semihydromorph condition. Steppe vegetation
was characteristic of these areas. On the low flood-plains, 2–4 metres lower,
abandoned channel sections and oxbows were common. They were seasonally
inundated, and the area was either covered by open waters or had a moor-
swamp vegetation.

Fundamental changes were brought about by the regulation of the river:
it changed the mechanism of the stream, forced the river into embankments
and, from Budapest down to the region of Dunaujváros, into two beds. Con-
nected with the above were changes in the quantitative-qualitative features of
the natural processes and also an alteration in the ecology of the whole region.

a) The Danube is restricted by dams into narrow belts and thus floods in
the main channel culminate at higher water level than formally. (This refers
to the main channel at Budafok, and does not affect the Ráckeve-arm of the
Danube which is regulated by the Kvassay flood gate). Erosion is more active
in the restricted channel, and more humid ecological conditions characterise
this area. (On the banks more homogeneous successions developed: *Salix, Po-
pulus, Alnus*-species and *Cornus sanguinea, Crataegus* etc. At the same time the
possibility of the homogenization of the natural processes increased in the flood-
free areas. Former yearly inundation of abandoned meanders ceased on the
high flood-plain and their role was taken over (though on a smaller scale) by
the inland waters which were linked with the now higher floods of the Danube.
Thus the meanders were gradually drying out as both qualitative and quanti-
tative factors played a role in the direction of their development, not to men-
tion the most, important event — the reduced frequency of floods. This result-
ed in the following: the former river-beds became oxbow lakes, and began to
dry out gradually. They were infilled by mineralogic and organogenic sedi-
ments and the prevailing ecological conditions became somewhat more similar
to those of the upper flood-plains. On the upper flood-plains the danger of inun-
dation became remote and ceased to exist, and the natural steppe-forming
processes (in soil geography called chernozem dynamics) became apparent.

Flood-control regulations meant that additional areas were now available for agricultural purposes, and the range of possibilites for land use increased. The upper flood-plains could be used for a whole range of plant cultivation, for fruit and vine cultivation. This was made possible by the soil-forming rock as well as by the soils that had formed on these. However, it must still be taken into account in the course of agricultural utilization and when selecting suitable plants that the soils have a high carbonate content: it is the C-horizon which shows an especially high $CaCO_3$ content.

b) Agricultural use was gradually extended — as a result of protection against inundations and because of the process of filling up — to the lower flood-plain levels represented mainly by abandoned river channels (Fig. 4). First meadow cultivation, then the cultivation of agricultural plants that prefer moist soils was undertaken and, after the danger of inland waters had passed in spring, late sowing would follow. A gradually more and more intensive use of the land by man resulted (as a consequence of increased water consumption) in the drying out and filling up of the abandoned river channels. Regular ploughing causing the continual disturbance of the soil surface contributed considerably to the increase of soil erosion in the abandoned river channels, especially at their steep margins. The material degraded from both the higher levels and from margins of the abandoned channels accumulated in the former beds and the surface became more or less levelled. The whole area is now under cultivation. It has a rolling surface characterized by a shallow depression of 0.5–2.0 metres (Fig 4). Only in the southern part of the island — which was the most typical area of abandoned channel sections and of former meanders before the regulation of the river — there are still some oxbows filled with the inland waters at spring. Abandoned channels with narrow steep slopes of 2–3 metres are used as pasture or under meadow cultivation.

As on all surfaces with some potential relief energy under agricultural tillage, soil erosion increased in the area. Apart from the danger of soil erosion, there is, however, a future advantage, namely, the constant levelling off and filling up of the surface of the abandoned channels. This can only be attain-
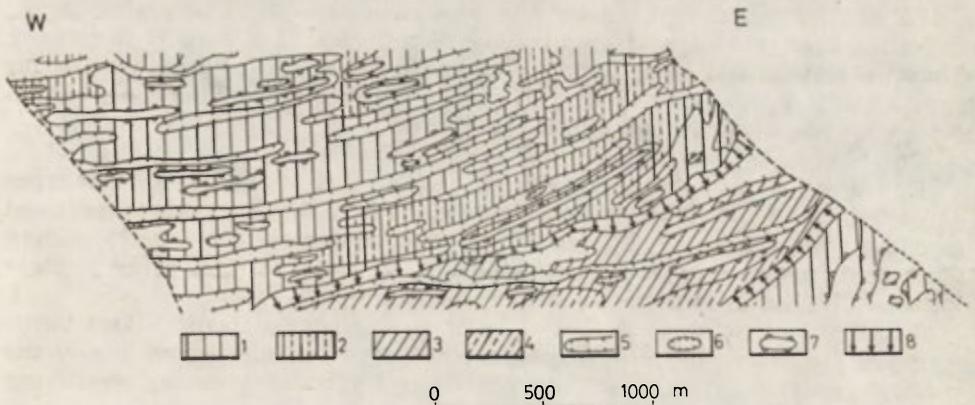


Fig. 4. Part of the geomorphological map of the model area showing the infilled abandoned river channel network, and separated into low and high flood-plains (constructed by L. Goczan, S. Marosi, S. Papp and. J. Szilard)

1 — upper flood-water level no. 1 (on average 98 m a.s.l.), 2 — upper flood-water level no. 2 (on average 97 m a.s.l.), 3 — lower flood-water level no. 1 (on average 96 m a.s.l.), 4 — lower flood-water level no. 2 (on average 95 m a.s.l.), 5 — infilled abandoned river channel, 6 — shallow depression (mostly infilled, abandoned channels), 7 — elevation, 8 — slope

ed by an accelerated soil-forming process induced partly by agricultural activity. This would result in the formation of anthropogenic soils in place of the present narrow, barren strips which, however, cover extensive areas.

4. Our brief discussion does not permit us to go into a further detailed analysis, and we must conclude with the following summary. In the model area and on the flood-plain, as a whole, embanking of the river considerably extended the possibilities of agricultural activity in the areas no longer endangered by floods. It sometimes led, however, to the formation of the kind of soil water table that promotes alkalization. We do not discuss this later problem in our present paper. As agricultural activity increased and the significance of linear erosion lessened under the new geomorphological conditions (decreasing relief energy) the role of areal erosion increased. This was influenced in the first place by the amount, frequency and intensity of precipitation. The effect of this could, however, be more marked on the disturbed cultivated surfaces and manifests itself in the form of increased soil erosion. This resulted in morphological changes. It is a seasonal phenomenon, but it must be reckoned within land use.

A consequence of agricultural activity on flood-plain surfaces is the so-called soil-climatic drying (L. Góczán, 1972b) due to agrotechnical methods and the different moisture demand of cultivated plants. This asserts itself in terms of soil dynamics by a gradual drying out of the soils: in our model area, and in the flood-plain area as a whole the hydromorphic and semihydromorphic processes become less important.

This process contributed to the formation of zonal soil types in the flood-plains along the Danube. Chernozems prevail and the meadow soils turn into chernozem-meadow and meadow-chernozem soils, and finally to chernozem.

*

It will be seen from the above that as a consequence of agricultural activity following river regulation and flood control, the former more diversified and varied soil genetic groups underwent important changes and the entire landscape ecology was fundamentally altered and became more homogeneous. At the same time, the natural productivity of the soils also were homogenized. Thus the genetic soil types could be treated by agricultural land use and for agrotechnical purposes as typical of a more uniform large homogeneous area (homogeneous, agroecotypes; Fig. 5).

Our method of investigation was as follows:

1. We determined the average productivity value of the genetic soil types and attributed point values to each (basic value figure). These values represent together with the modifying factors all environmental factors — including those occurring as a consequence of human activity. The total value of these latter are indirectly reflected in the genetic soil type.

2. All the environmental factors were also attributed point values including soil properties, the presence or absence of which influenced locally the average productivity value of the genetic soil type in question (modifying factors).

3. After combining the basic value figures and the values of local modifying factors, the total productivity value of a genetic soil type was determined.

4. The obtained values were classified and represented on maps (Fig. 5). The following general conclusion may be drawn: man's agricultural activity produces such far-reaching changes in the landscape (not only in flood-plain areas!) that it must be regarded as the most important landscape, and soil

forming factor. In agricultural areas some of the natural processes may cease to be active or their role may be reduced. The modifying effect of other natural factors may, however, assume particular importance because of the new conditions brought about by outside factors. These new processes were formerly either inactive or latent without the motivating force of cultivation and agricultural activity.
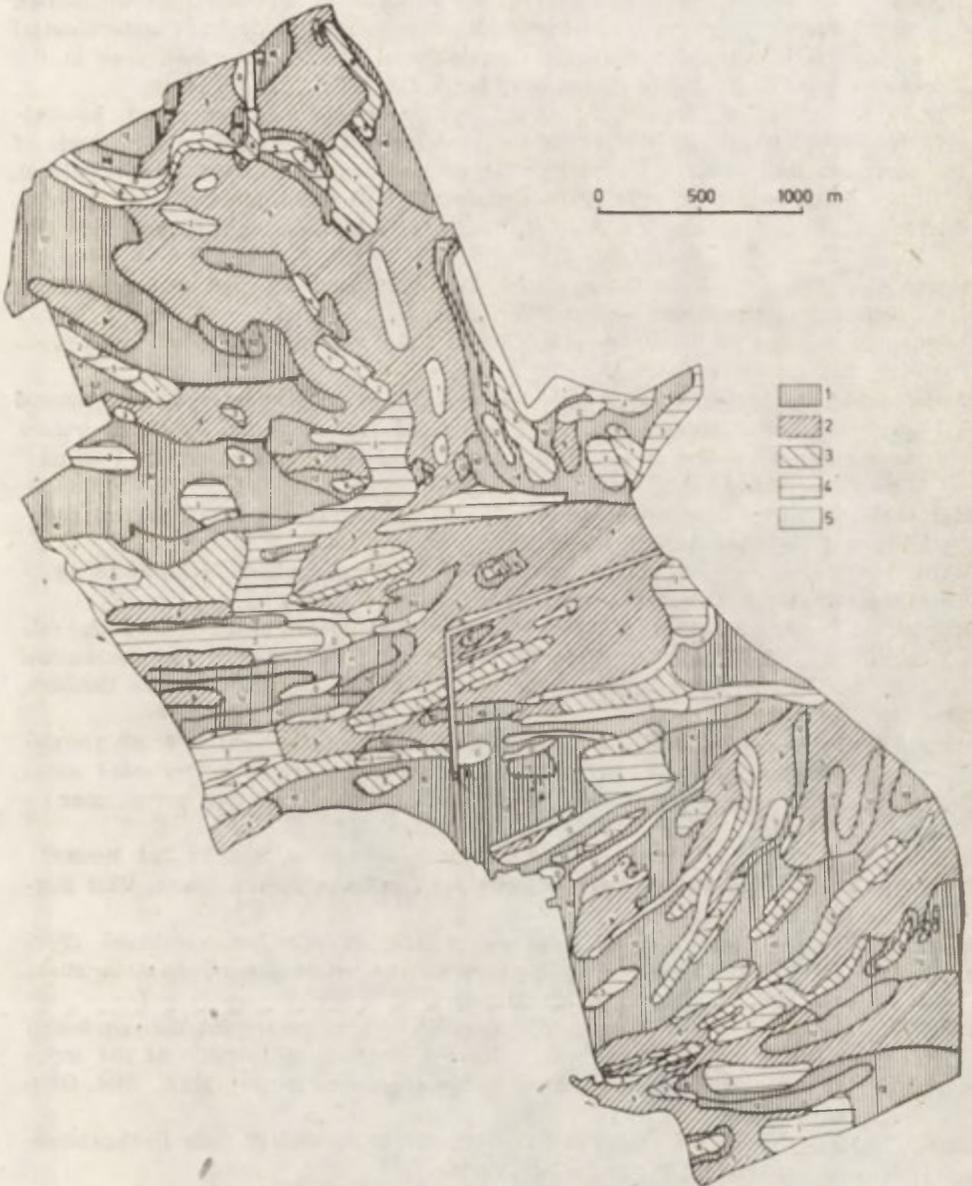


Fig. 5. Agroecological units of a typical flood-plain area (Lórév-Makád on the Csepel island) compiled by K. Molnár and S. Papp

Selected value classes for agroecological potentials (combined categories): 1 — outstanding potentials (10-12 points on map), 2 — good (8-9 points), 3 — moderate (6-7 points), 4 — poor (3-5 points), 5 — agroecological types with very poor potentials (0–2 points alloted).

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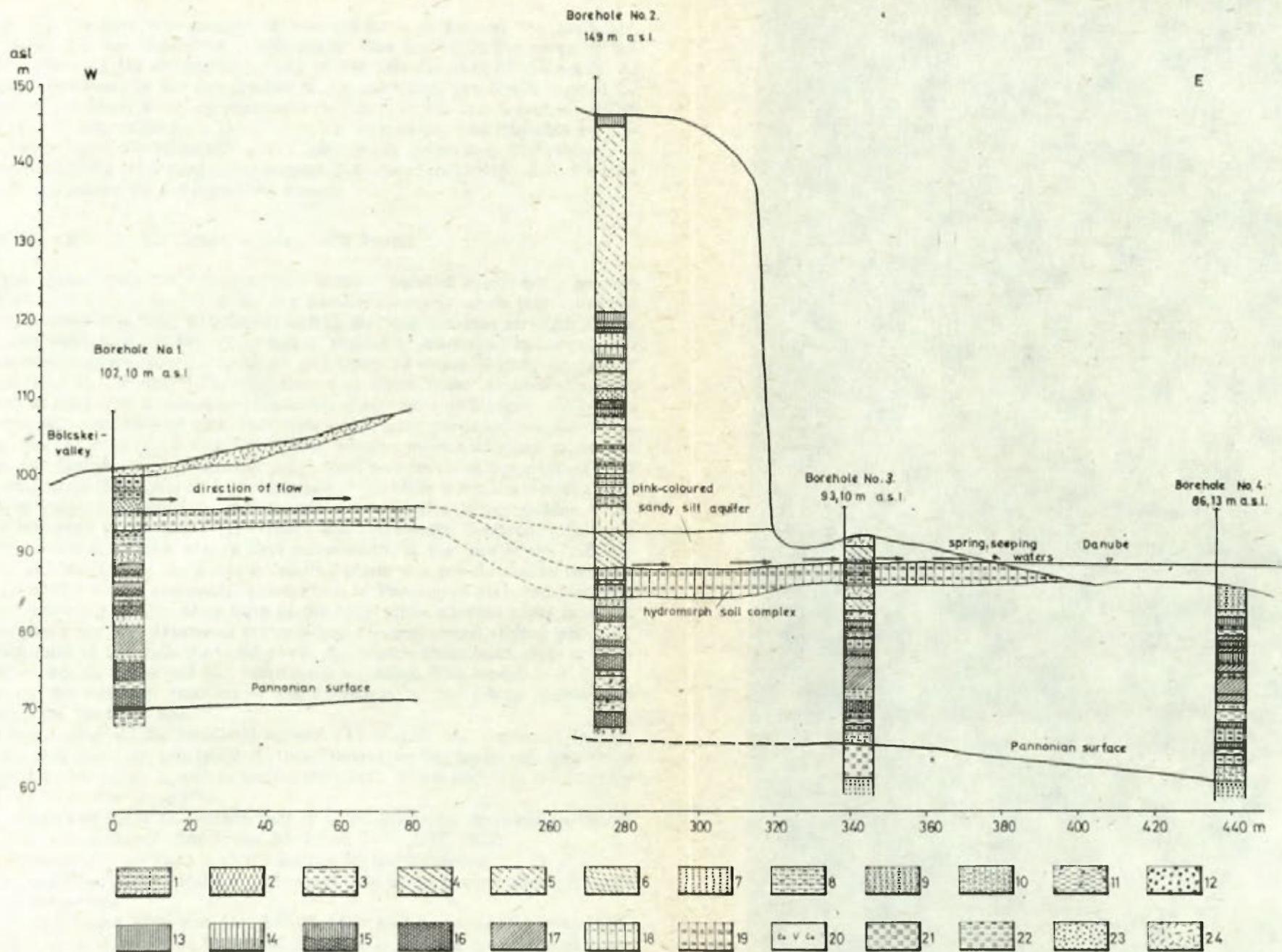
Fig. 2. Stratigraphic profile of the Also-Öreghegy' hill at Dunafoldvar on the basis of borehole data

A. Eolian sediments: 1 — sandy loess; 2 — loess; B. Colluvial, deluvial sediments: 3 — sandy loess, stratified fill of a buried derasional valley; 4 — pink-coloured fine sandy-silt; 5 — stratified loessy-sand; 6 — stratified loess; C. Fluvial-proluvial sediments: 7 — sand; 8 — silty fine sand; 9 — silty sand; 10 — Fe, Mg coloured patches in clay; 11 — brownish-yellow $CaCO_3$ concretions in silty-clay; 12 — sandy gravel; D. Recent and fossil soils: 13 — humus carbonate soil; 14 — steppe-type soil; 15 — chernozem brown forest soil; 16 — brown forest soil; 17 — semipedolite; 18 — hydromorphic soil; 19 — alluvial marshy soil; 20 — $CaCO_3$ accumulation; E. Pannonian: 21 — grey-yellow clay; 22 — grey-yellow silty sand; 23 — snd; F. Anthropogenic constructive forms: 24 — anthropogenic fills

# CHANGES IN THE GEOGRAPHICAL ENVIRONMENT AS A RESULT OF OPEN MINING

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Land features formed as a result of open mining play an important role among anthropogenetic forms which occur in the Polish landscape. They consist of all kinds of deep pits of various sizes, slope pits, slope recesses, and a number of other forms. According to the resources which are being exploited, the type of land where the mining takes place (regional and morphological), and the method of exploitation, the resulting anthropogenetic forms will all be very different. The degree of interference with and influence on the surrounding environment will also differ. With reference to the method of exploitation the following question arises: are dumping of the overburden and draining of the bed necessary to obtain a given mineral?

Generally, the above forms may be divided into forms which only locally influence the area and forms of some wider influence on the surroundings. Changes caused by open mining of brown coal are one of many examples of the latter group. The detailed mechanism and range of changes are shown in Fig. 1.

However, according to the author it is not enough to establish facts evidencing man's interference with the geographical environment. The geographer's task is to develop methods of forecasting changes in the geographical environment, and then to determine the forecast itself. That is in agreement with the basic principles for the development of physical geography, and with the tasks set before that discipline by the economic needs of a country (Z. Chojnicki, B. Gruchman, S. Kozarski, 1967; S. Kozarski, 1975).

The author would like to make some remarks about methods forecasting changes in relief on the basis of investigations carried out in the Konin Coal Basin and in some coal basins in the GDR. The starting point for analysis of future changes, and thus analysis of relief forecasting, should be a detailed knowledge of the original situation. However, in the case of mining on a large scale, this requirement has not always been met. Knowledge of the present situation must include the geomorphological characteristics of the area (map with description) of the future basin against a wider background in order to indicate or exclude some relationships and interdependent factors. The area of the coal basin itself should have a detailed map of its slopes. But because of strong interrelations between factors of the geographical environment, forecasting of changes in relief will be accurate only when one takes into consideration the relationship of relief to geological and hydrological conditions, or to other elements (L. Kozacki, 1965, 1972). It will also be very important to know the technological background to the mining activities and in particular,

— Possibility of cyclic recordings. Repeating of recordings allows for a close observation of changes, which is the basis for discovering tendencies, and hence it provides some basis for forecasting.

Because of these requirements it is impossible to use the method of the instrumental topographic photograph, which is very detailed but takes too much time and does not allow everything to be recorded at once. Since a picture of the open mine changes very quickly, above-ground photogrammetry avoids some negative features of the previous method. However, it should be taken into account that so-called "dead fields" may occur, resulting in a incomplete picture.

The method that secures cyclicity and allows forms and phenomena to be recorded at once in the whole of the area under investigation is the use of photogrammetric aerial photographs (Liedtke, 1963; L. Kozacki, 1969). At the same time, the detail obtained allows one to detect the development or alterations occurring in microrelief which is so characteristic of anthropogenetic forms (M. Z. Pulinowa, 1972; J. Repelewska-Pękalowa, 1973). When it has been decided that aerial photography will be the main method, still the other two methods cannot be excluded. They may be used as additional methods in fragmentary investigations or in investigations of some narrower thematic range. The use of aerial photography is further supported by the fact that it records all the processes and phenomena occurring on the surface and in sub-surface zones, this enables one to use the material obtained for analysis and to develop forecasting of changes within other areas of the geographical environment. This refers to surface waters, to the uppermost level of underground waters, to the surface geological structure, which altogether contribute to the knowledge of hydrological and geological-engineering conditions (R. Beaver, J. Wood. 1974). This also refers to soils and vegetation.

From the aforementioned wide application of aerial photography arises the question: in what periods should photogrammetric flights take place, so that the material could be used for various analyses. As can be seen from the accompanying plan of stages for the forecasting of changes in relief, photogrammetric flights for that type of forecasting should be made in the following periods (phases):
— after recognition of deposit, before exploitation (I),
— after heaping of the outer dump (II),
— after the end of draining and the end of exploitation (III),
— alter all reclamation is finished (IV).

It seems that moments captured on aerial photographs will be crucial not only for analysis of relief but also for analysis of other elements of the geographical environment. Only during the preliminary photographing it should be remembered that photographs should be taken not only before the mining itself (opening dig) but also before preparatory works, such as draining of deposits, shifting of flows, surface draining, buildings of roads, forest clearing, etc. With regard to the last photogrammetric flight, it may be necessary to plan the date with more care, or even to plan an additional flight so that the analysis, and therefore the forecasting, would be complete.

In the Konin Coal Basin the brown coal is exploited from various pits started at different times, so that they are at various stages of development. Therefore, while taking aerial photographs of one which is at some definite stage of development it is possible to find a picture of another pit which is at another stage or at an intermediate stage. The documentary material is then greatly enriched.

On the basis of aerial photographs of the area of the open pits "Niesłusz" and "Gosławice" taken at the third stage of exploitation (that is after the end of draining and exploitation) a map of the changed relief with some elements of a morpho-dynamic map has been made (Fig. 3). Although in the normal cycle of a study the appended map is a part of the whole which enables us to see changes in the relief and its dynamics, a proper sign showing the dynamics also gives a good idea of the whole. The first application of that principle is a differentiation of artificial elements from natural ones by means of colour. All features of anthropogenetic relief, which in that case are connected with a direct mining activity, are marked in blue. These are surfaces of outer dumps, surfaces of inner dumps, slopes formed due to dissection of the surface during removal of overburden, traces of removal of brown coal deposits or overburden, surface of unlevelled ground dumping, longitudinal dumps and slopes of rolling-indented slopes. Contour lines illustrating the relief of areas not changed by mining and all forms and signs which were formed and resulted from changes in the relief after the anthropogenetic activity has been finished, should be marked in brown. This is in agreement with the accepted rule for the indication of relief on topographical maps. In most cases brown signatures occur in combination with blue ones, which, on the one hand, underlines the character of a given feature or phenomenon, and on the other hand, according to the author, the morpho-dynamics of the relief are obtained.

The graphic picture of signatures in some degree has been based on Keys to a geomorphological map, whereas new signatures have been elaborated by the transformating of the picture presented on aerial photographs.

The time period during which the problem undertaken was studied did not allow for a complete observation of the phenomenon. This meant that it was possible to give a diagrammatic account of phase III only. The later picture of the relief after mining, and thus the general dynamics of the relief, and detection or determination of the basic zones, were possible only on the basis of studies comparative to post-mining areas in the German Democratic Republic. Traditions of open mining of brown coal in the GDR are very old, and that is why features connected with that kind of human activity are quite numerous. Mines and post-mining areas in Lower Lusatia are the best area of reference for purposes of comparison (J. Pilawska, 1965, 1967). As follows from the initial part of the article, outer and inner dumps and final basins occur on the site of the open mine. The problem of the outer dump consists in the instability of its slope zone, and forecasting should take into account an increase in the length of the foot of the dump. There is no doubt that it will be influenced by the surface and height of the dump, the manner of overburden heaping, the manner of levelling of the upper surface, and by the kind of material dumped. It should be stressed that plants introduced there will play an important role in keeping the scarp stable. It will be strongly influenced by man's activity and a proper choice of plants. From the experiments carried out by the author it follows that in spite of proper reclamatory operations and proper choice of plants, the range of the outer dump foot has finally increased by 100%. Whereas processes of erosion, for obvious reasons, will largely affect the top zone of the dump. With suitable inclination, draining and economy that influence may be minimal. However, because this form is very specific the regime must be controlled by man.

Within the inner dump the problem of uneven subsidence of dumping and later of levelling material may occur, which results in the secondary rolling of the area. There may also occur small suffusional basins which lead to local wetness of the surface. In order to foresee tendencies, and in some degree also

the extent of changes, the material collected in the second and third phases of forecasting will be used. It would also be advisable to record the movement of the ground from the point of view of lithological separation both in the horizontal and in the vertical sector. Particular attention should be paid to that side of the inner dump which will close the final basin. The process of change of relief within slopes of the outer dump is most intensive in the initial phase after heaping. But with the passage of time one may observe stabilization of the ground mass and a decrease in the intensity of the process and even its cessation. However, within scarps of the final post-exploitational basins, after their formation (dissection of the surface or heaping of the inner dump) there occurs quite a long process of mass movements (starting from the second phase) with signs of a gradual stabilization. The stabilization is stopped in phase IV when draining of the former area and the deposit also ceases. Raising of the underground water level and repeated watering of sediments within the "mainland" * and watering of the inner dump result in a renewed intensity of ground movement. Furthermore, the post-exploitational basin is filled with water and at the same time there occur processes of surface and underwater feeding, oscillations of the water level and processes of rolling. Altogether they strongly influence the slope area and unstable ground masses of the inner dump. On the basis of the evidence gathered in the Lower Lusatia Basin it may be said that it is a very intensive process and often catastrophic in its effects. It makes cultivation of post-mining areas very difficult. That is why the author marked places worthy of note with points or modal zones. In this case the usefulness of forecasting is quite evident. Gathering of the basic information about the original relief, geological structure, hydrological conditions, and particularly about the mechanism and dynamics of the underground waters of the first and deeper levels during the main stage of forecasting and completion of observations during further stages make a basis for the optimum forecasting of the relief development in the area discussed. However, from the point of view of economy the point is to reduce changes in relief which are so damaging and catastrophic. The stage of basic forecasting should determine the character of future utlization of adjacent areas together with some early change of vegetation, which may be of a decisive character there. It should also determine the necessity and range of hydrotechnical operations. Thus we see that forecasting should serve reclamative operations. There is no doubt that reclamation must be based upon forecasting of changes in relief and in other elements of the geographical environment, so that post-mining areas can be utilized in the best possible manner.

It may also be suggested that some elements of forecasting should be included in the general plan of mining operations, and particularly in the plan of distribution of particular physical features since their topographic and environmental situation is not without significance for the future formation of the relief. This especially concerns the outer dump and post-mining final basin. At the present time, the programmes which have been developed for reclamation are only partially based on forecasting studies, which makes them difficult or sometimes even impossible to realize. Only a total integration of the restorative programme in post-mining areas, on the basis of forecasting studies, with the whole spatial design can lead to a real restoration of areas devastated during mining works.

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* This term is used by the author to refer to the area which has not been mechanically changed during mining works.

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