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SOIL EROSION MODELLING IN THE MBULUZI RIVER CATCHMENT (SWAZILAND, SOUTH AFRICA)

PART I
MODELLING THE DYNAMIC EVOLUTION OF GULLIES

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In southern African countries soil erosion and the related problems like water quality issues or decreasing soil productivity are the main topics affecting the inhabitants of rural and urban areas. Therefore the problems related to soil erosion were more and more focused in the recent past. This can be also documented by a increasing number of erosion studies and the development and application of erosion models. Nevertheless gully erosion phenomena have been completely neglected in erosion modelling. Thus because the development of erosion models was focused on regions with intense agriculture of developed countries on the one hand and because of the spatial and temporal heterogeneity of gully erosion processes on the other. This study regards the identification of gully erosion forms and processes in the Mbuluzi-river catchment (Kingdom of Swaziland) using the Erosion Response Units concept (ERU). The following modelling of the gully erosion was done successively with a physically based dynamic gully model. The input data were obtained by remote sensing techniques (API method) and GIS-analyses. The example from Southern Africa show that the methods applied are able to identify areas affected by gully erosion. Furthermore it is possible to estimate the amount of soil loss due to gully erosion, which is not taken into consideration with the USLE-type models.

KEY WORDS: Gully erosion, Erosion modelling, Erosion Response Units, Swaziland.

INTRODUCTION

Erosion phenomena caused by population growth and the subsequent overstocking of grazing land as well as the clearance of natural bush vegetation are quite severe problems in the «Middleveld» of Swaziland. Especially the erosion of unconsolidated or weakly cohesive substrates has resulted in the formation of extensive gully systems. In the central «Middleveld» the density of gullies can reach 20 gullies within an area of 5.0 km^2. Some of them cover areas of up to 5 ha and they are often more than 25 m deep (WMS Associates 1988). Based on the given circumstances only little is known about the dynamics of gully development in this area.

The study presented herein deals with the identification and modelling of gully erosion features and processes in the Mbuluzi river catchment (Kingdom of Swaziland)

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and is part of the interdisciplinary EU-funded project *Integrated Water Resources Management System (IWRMS)* for semi-arid catchments of Southern Africa. This paper follow the methodological part regarding the identification of erosion forms and processes based on the Erosion Response Units (ERU) concept published in the last issue of this journal (Märker & *alii*, 2001a).

Erosion processes and forms caused by water are mainly influenced and interlinked by the hydrological dynamics of a drainage basin. An innovative approach to characterize erosion processes caused by water and their integrated dynamics was introduced by Märker & *alii* (1999, 2001a) and Flügel & *alii* (1999) with the concept of *Erosion Response Units* (ERU).

In this study the ERUs are used on one hand to identify areas subject to gully erosion and as modelling entities for gully erosion simulations on the other. Remote sensing techniques were applied to get information about the distribution of the physiographic and anthropogenic catchment characteristics (land use, settlements, digital elevation models, etc.). Furthermore this information was used for the parameterisation of the physically based gully erosion models which have been developed for similar environmental conditions (see Sidorchuk, 1998, 1999). These models are accounting for the two development stages of a gully. During the period of gully initiation the gully channel formation, following the drainage network, is very intensive and consequently the morphological characteristics are far from stable. This stage comprises only about 5% of the entire gully lifetime (Zorina, 1979), but already more than 90% of gully length, 60% of its area and 35% of the gully's volume are formed in this period. In the remaining 90% of the gully's lifetime the morphologic conditions are nearly stable. In this study the dynamic gully erosion model was applied to simulate the first stage of gully development. Model validation and verification were carried out using detailed information on gully system time series and by ground checks.

LOCATION AND PHYSIOGRAPHY OF THE STUDY CATCHMENTS

The study catchments are drained by the upper Mbuluzane River (contributing area: 221 km^2) and the Mhlambanyoni River (contributing area: 42 km^2) (fig. 1). Both

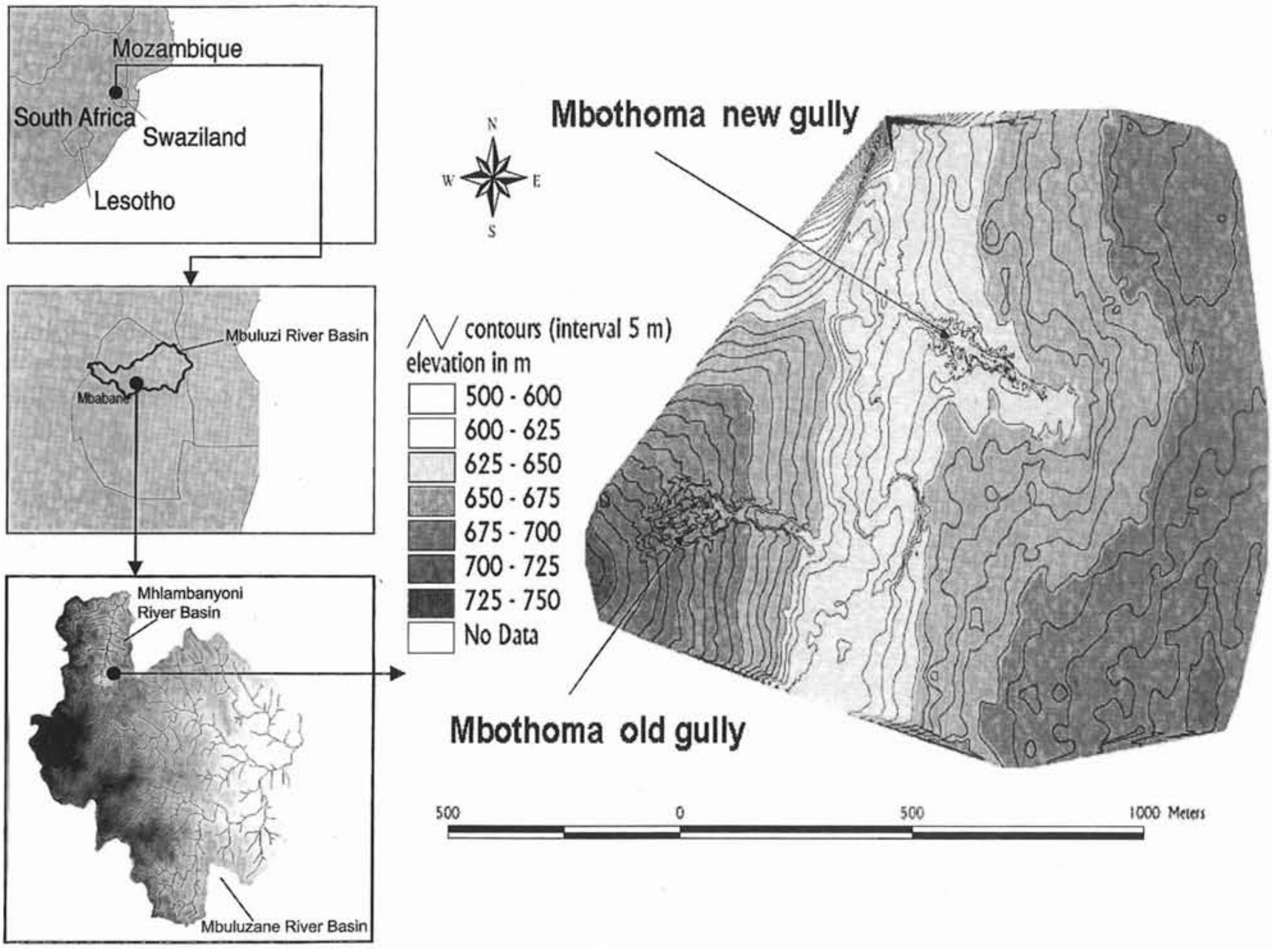

FIG. 1 - Location of the Mbuluzane river study catchment.

rivers are tributaries of the Mbuluzi River and they fall into the physiographic region of the upper Middleveld with altitude ranges from 610 to 760 meters a.s.l. and median slopes of 12 percent (Mushala & *alii*, 1997). The geology of the Middleveld consists in granite and granitic gneisses with outcrops of dolerite and gabbro. The region is characterised by deep, acid and well drained red and yellow ferrisolic and ferrallitic soils, often with stone lines (Murdoch, 1970). The mean annual rainfall ranges from 700 to 1200mm, with the main rainfall in summer (October to March) primarily as thunderstorms. Kiggundu (1986) calculated a rainfall erosivity (EI_{30} in kJ mm/m^2 hr) of 450 (after Wischmeier & Smith 1978).

Within the Mhlambanyoni test catchment the Mbothoma area, ca.15 km north of Manzini (26°20'S; 31°23'E) was chosen as a characteristic test site for gully erosion studies. It is a densely populated area and overgrazing is widespread. The dominant land use on this subsistence-small-scale farming land is pasture (fig. 2). The lithology is composed of a thick granodioritic saprolite layer and a system of amphibolite and serpentite dykes (Hunter & *alii*, 1984; Mushala & *alii*, 1994; Scholten & *alii*, 1995).

MATERIALS AND METHODS

To identify areas affected by gully erosion the concept of Erosion Response Units was used (see Märker & *alii*, 1999, 2001a; Flügel & *alii*, 1999). The ERU delineation in the Mbuluzi river catchment was carried out with the analyses of stereo-aerial-photographs, orthophotos and GIS. For the classification of the erosion features and the subsequent delineation of erosion response units, the erosion type, the degree and extent of erosion, as well as the density of the erosion features were mapped based on 1996 aerial photographs at 1:30.000 scale. Therefore the adapted method of Van Zuidam (1985) was applied (see Märker & *alii*, 2001a, b).

The ERUs deliver information about the spatial distribution and intensities of erosion features and processes active within the study area.

Based on this data a high density of gullies have been identified in the Mhlambanyoni and upper Mbuluzane River basin. Within the Mhlambanyoni catchment the Mbothoma gullies were chosen for a more detailed research. The evolution of the gully system subsequently has been modelled using a physically based gully erosion model developed for similar environmental conditions (Sidorchuk, 1998, 1999).

Dynamic gully model

The model used in this study calculates the first dynamic development stage of the gully flowline network.

The rate of gully erosion is controlled by water flow parameters (velocity, depth and turbulence) and soil parameters such as texture, soil cohesion, shear stress, Manning roughness and vegetation cover. These characteris-

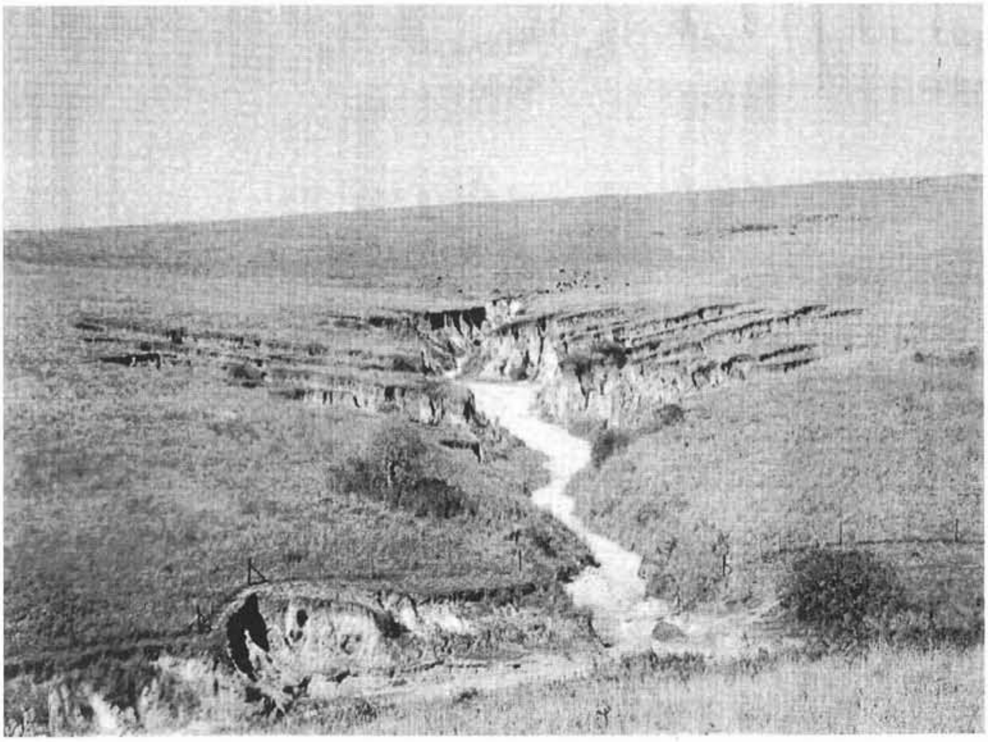

FIG. 2 - Dynamically developing gully in the Mbothoma study area (Mbothoma new gully).

tics are combined in equations of mass conservation and deformation, which can be written in the form

$$\frac{\partial Q_s}{\partial X} + \frac{\partial AC}{\partial t} = C_w q_w + M_0 W + M_b D - C_0 V_f W \quad (1)$$

$$\left(1-\varepsilon\right) W \frac{\partial Z}{\partial t} = C V_f W - M_0 W \quad (2)$$

Here Q_s = Q C sediment discharge (m^3/s),
Q = water discharge (m^3/s);
X = longitudinal coordinate (m);
t = time (s);
C = mean volumetric sediment concentration;
C_0 = volumetric sediment concentration in the near bed layer;
A = - flow cross-section area (m^2);
C_w = sediment concentration of the lateral input;
q_w = specific lateral discharge;
M_0 = upward sediment flux (m/s);
M_b = sediment flux from the channel banks (m/s);
Z = gully bottom elevations (m);
W = flow width (m);
D = flow depth (m);
V_f = sediment particles fall velocity in the turbulent flow (m/s).

The first term in the left part of equation of mass conservation (1) defines the sediment budget in the channel reach, the second term is the sediment storage in the flow. The right part of (1) defines the sediment flux: the first term describes the lateral flux, the second one is upward flux, the third one the sediment flux from the banks, and the fourth one the downward flux. The equation of deformation (2) defines the change of gully bottom elevation according to the sediment budget. The sediment storage in the flow is usually very small and can be neglected. In this case the equation (1) is a first order ordinary differential equation, and equation (2) is a first order partial differential equation with variable coefficients. The solution of these equations depends on the form of the terms, which describe sediment fluxes. In this study the terms and solutions described by Sidorchuk (1999) were used.

Model adaptation to the Mbothoma situation

Generally the settings of the dynamic gully model were taken from Sidorchuk (1999). This is the case for the description of the lateral and upward sediment fluxes, sedimentation and bank erosion. The processes of gully sidewall transformation were much more complex due to the combinations of weathering, mass movement and rill erosion. Therefore the inclinations of the stable gully side walls (angle of repose) were estimated empirically from measurements of slopes of the old stable Mbothoma gully (see fig. 3). The processes of gully incision can be described with equation (3) that calculate the bed elevations Z. It takes the form of a transport equation taking into account erosion and deposition processes

$$\frac{\partial Z}{\partial t} - a \frac{\partial Z}{\partial x} - V_f C = 0. \quad (3)$$

Here a = kgρq, (k = erosion coefficient, g = acceleration due to gravity, ρ = water density and q = specific discharge). Using this equation the on-site topography of the gully (elevation Z) can be recalculate during the modelling process because it takes into account the feedback phenomenon between slope transformation and change of channel flow characteristics. Equation (3) can be solved numerically, for example with the explicit predictor-corrector scheme of Lax-Wendroff (Sidorchuk, 1999).

FIG. 3 - Gully with stable morphology in the Mbothoma study area (Mbothoma old gully).

Input data for dynamic gully model

The input information to run the dynamic gully model consist of geomorphological and geological parameters, vegetation cover information and hydrological information subsequently described in detail.

Topography is characterized by elevations and distances from the gully mouth in *n* points of the longitudinal profile of each flowline on initial slope (including existing gullies). The water discharge change in time (hydrograph) was calculated for all these points with a hydrological model (see below). In the model multilayer soil properties are used comprising input information for each layer about the elevations of the base in the same *n* points; soil density; cohesion; angle of internal friction; diameter of stable aggregates; water content and content of thin roots.

DEM analysis

To obtain the morphological input data for the gully model a photogrammetric stereoanalyser (Planicomp P33, Carl Zeiss Jena) was utilised to get digital elevation data from the 1960s, 1970s and 1990s aerial photograph series with a resolution of 1 m by 1 m. The georeferencing was done with 1:5.000 scale orthophoto maps. The DEMs were used for flowline network evaluation. A procedure was drawn up for the filling of closed depressions using a maximum gradient method with eight possible flow directions. The possibility of setting the preferable direction was provided to allow the estimation of the influence of out-of-scale features such as small roads or ploughing up. The catchment area of each point was calculated as the sum of pixel areas following the gradient or flowline linked to this point upwards. For the Mbothoma test gully basins the following stratigraphic and morphometric features were delineated for each flowline from the DEMs:

- subcatchment area;
- subcatchment length;
- profile of the initial surface of the basin (distance and altitude) along the flowline;
- contributing drainage areas for all points along the flowline (distance and area);
- initial profile of the surface (distance and altitude) of each lithological layer along the flowline.

Fig. 4 shows the DEM of the Mbothoma gully system (initial surface) and the calculated drainage lines. The delineation of the lithological layers was done by the triangulation of field-measured sample spots, taking into account ground truth information. The lithologic information for each layer (tab. 1) comprise soil texture, bulk density and saturated hydraulic conductivity values obtained by ring infiltrometer analyses as well as literature data concerning cohesion (Hunting Technical Services, 1983; Murdoch, 1970; Mushala & *alii*, 1994; Scholten & *alii*, 1995; WMS Associates, 1988).

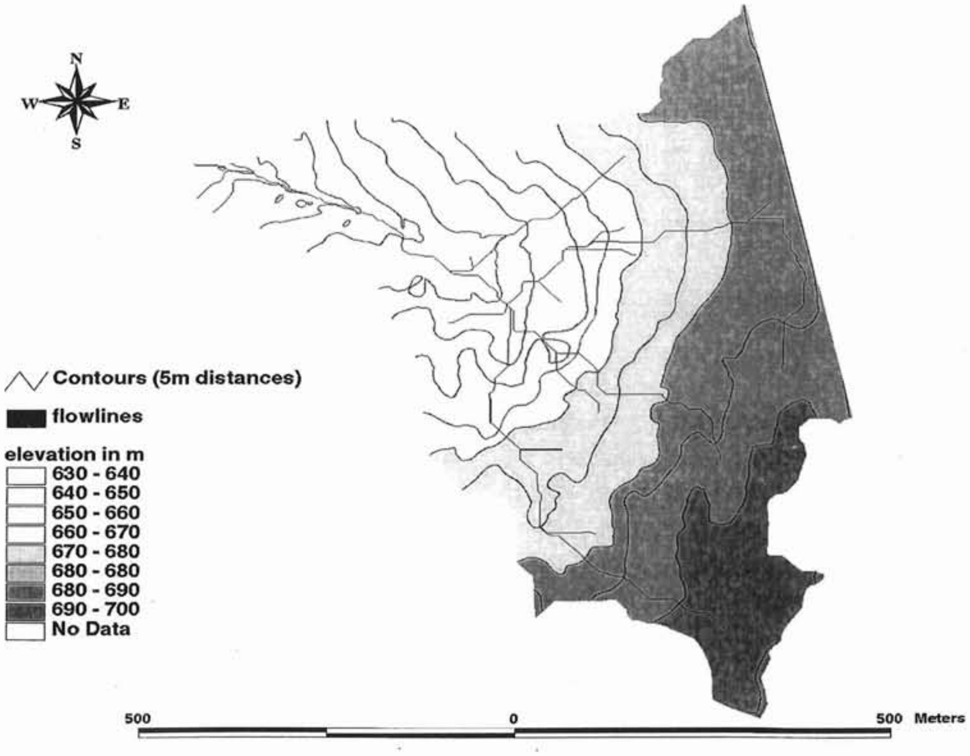

FIG. 4 - The DEM of the Mbothoma gully system (initial surface of the year 1960) and the calculated drainage lines.

TABLE 1 - Soil parameters of the lithological layers of the Mbothoma gully catchment

	Topsoil (~0.2 m deep)	Subsoil (up to 1.5 m deep)	Saprolite (more than 60 m deep)
Sand (%)	30	40	50
Silt (%)	20	30	40
Clay (%)	50	30	10
Bulk density (g/cm^3)	1.1 - 1.5	1.1 - 1.5	1.2
Cohesion (kPa)	4.5 - 9.0	4.5 - 9.0	3.14
Saturated hydraulic conductivity (cm/day)	0.5-1.8	0.5-1.0	1.0-4.4

As the geological structure of the Mbothoma gully catchment is relatively uniform (saprolite), soil texture do not change along the flowlines, but with the depth of incision (small horizontal variance). Consequently the τ_{cr} value were changed along the flowlines during the calculations, mainly at the points of texture change.

Runoff Estimation

The dynamic model uses daily values of discharges, which form the gully cut. Therefore runoff was simulated for a period of 45 years with the «agrohydrological modelling system» (ACRU) (Smithers & Schulze, 1995). The ACRU model uses an adapted SCS procedure (USDA 1985; Schulze & *alii*, 1993), designed to use daily rainfall input as the driving mechanism. The modelled runoff on a daily time step resolution have been provided by the Department of Agricultural Engineering, University of Petermaritzburg (RSA) for three subcatchments of the Mbuluzi River. For the upper Mbuluzane river catchment (GS3 runoff gauging weer) the regression between observed and simulated runoff show an r^2 of 0,84. Finally using this data the daily runoff depths (mm) were calculated for the smallest subcatchment, the Mhlambanyoni river basin with an area of 41.6 km^2 and for Mbothoma new gully (fig. 1, 2).

Daily runoff values are used in the main equation (3) and to calculate all hydraulic characteristics. The upper part of the slopes (above 650-655 m) is under hortonian-type runoff, and only quick flow was used for these areas. For the lower part of the slopes, where base flow is formed by ground water seepage, the whole runoff was used to calculate gully morphology.

Dynamic model calibration

The rate of deposition on the dykes in the Mhlambanyoni river channel and in the Mbothoma gully itself is neglectable small, consequently equation (3) was used in the form:

$$\frac{\partial Z}{\partial t} - k\rho g q \frac{\partial Z}{\partial x} = 0. \quad (4)$$

The erosion coefficient k is positive when flow velocity is greater than the critical value U_{cr}, and is zero when flow velocity is lower than critical velocity. So values of k and U_{cr} must be calibrated for erosion in saprolites (within the gully) and in amphibolatis (in the river). Calibration was performed by modelling the conjoint evolution of the longitudinal profiles of the Mhlambanyoni river channel and the Mbothoma gully for the period 1960-1990. The calculated and observed profiles fit best with $k = 0.0002$ and $U_{cr} = 0.72$ m/s for amphibolites and with $k = 0.006$ for saprolites. The value of the near bed critical velocity $U_{cr} = 0.18$ m/s was estimated for the saprolites within the Mbothoma-old gully with the stable gully model (Sidorchuk & *alii*, 2001 in press). This value was used for Mbothoma-new gully (which cut the same type of soil) in the dynamic gully modelling. The critical velocity for the topsoil layer with vegetation roots in Mbothoma gully-new was estimated as 1.3 m/s. The inclinations of the stable gully side walls (angle of repose) were estimated empirically from measurements of slopes of the old stable Mbothoma gully (see fig. 3). At the lower 200 m of this stable gully the mean inclination of the walls is $\phi = 49°,2$ (with standard deviation 7,4 for 35 measurements).

RESULTS

Applying the ERU-concept the erosion features and processes recognized in the Mbuluzi catchment are mainly rill-interrill erosion and deep linear erosion (gully erosion). Severe gully erosion was identified mainly in the upper part of the Mbuluzane River catchment and in the Mhlambanyoni catchment. The Mbothoma gullies appear in the highest erosion class. About 8% of the Mhlambanyoni basin is directly affected by severe deep gully erosion (classes 4, 5 and 6) (see Märker & *alii*, 2001b). It should be noted that the zone of intensive erosion is situated along a north - south running system of amphibolite/ serpentinite and dolerite/ granophyre dykes. The main lithology consists of highly erodible saprolites (Mushala & *alii*, 1994; Scholten & *alii*, 1995). It is a densely populated area with a high livestock concentration. Consequently overgrazing occurs, especially on communal land like the Mbothoma area. Cattle tracks and pathways are visible in the aerial photographs and analyses of different time series show that gullies often develop along these pathways and tracks (see also WMS Associates, 1988). The high density of gullies identified with the ERU method in the Mhlambanyoni and upper Mbuluzane River basin was the reason for the more detailed research on gully erosion processes and dynamics in this area. Therefore the Mbothoma gullies (figs. 2, 3) were chosen as test gullies for model application.

In the gully catchment the soil cover varies from less than 15 cm on the top of the contribution area to more than 1,50 m in the colluvial parts of the slopes. The gully system on communal land under pasture has developed in the drainage line of a former wetland area, caused by a crossing amphibolite dyke. Side valley gullies are growing along cattle paths which cross this creek. Part of the gully contribution area was fenced in the late 1980s. However the entire upper part of the slopes are still under pasture and they are heavily overgrazed. The confluence of the Mbothoma new gully, with a catchment area of 41.8 ha, with the Mhlambanyoni River is located at 3800 m distance from the river mouth. The gully was formed on the convex - concave initial slope (fig. 3). First analysis of an aerial photographs series (1960, 1971, 1996) show that the recent (1996) gully bottom has a uniform main trunk which is about 490 m long, with short side tributaries. The entire gully length is about 44% of the gully catchment length, and now the gully occupies only 1.5% of the catchment area. The main gully is 7-16 m deep, has a U-shaped cross-section with bottom widths of 13-20 m and steep sidewalls. The gully is at the first stage of the rapid backward growing of its length (fig. 5).

In 1960 the gully was about 180 m long and 5 m deep and long narrow troughs continued on the slope above the gully head. In 1971 the gully length was about 200 m. The depth of the gully bottom increased to 12 m and also the upper trough become 4 m deeper. In 1990 the gully was already 400 m long and 14 m deep, and in 1998 it was 490 m long. Consequently in the first 11 years (1960-1971) the average gully length growth rate was about 2 m per annum, but the depth rapidly increased for 0.64 m/a in the gully and for 0.36 m/a in the trough. During the period 1971-1998 the gully length increased for 10-11 m/a, and its depth increased with a rate of 0.14 m/a in the gully and 0.4 m/a in the trough.

The gully erosion in the Mbothoma area seems to be induced by an abrupt lowering of the erosion base. Indeed the aerial photo series show that the recent gullies in the Mbothoma area have been developing since the 1960s/ 1970s. The longitudinal profile of the Mhlambanyoni river has step-pool pattern, with pools developed in granodioritic saprolite, and steps formed at amphibolite dykes (fig. 6). In 1960s the well defined steps occur only at the headwater of the river. Up to 1990 the significant erosion of the river bed highlighted the dykes at the lower reaches of the river. At a distance of 2600-4800 m from the mouth of the Mhlambanyoni River the mean rate of river bed lowering was 0.68 m/a for the period from 1960 to 1990, but the development was non-uniform in time. In average for the whole section the rate of river incision was 0.25 m/a from 1960 to 1971 and 0.93 m/a from 1971 to 1990. Locally (for example, near the mouth of Mbothoma new gully) the rate of river bed erosion was the same for both periods, or even more intensive during the first period (fig. 6). In the years 1960-1990 the erosion of granodioritic saprolite was generally more intensive (0.77 m/a), than the erosion of amphibolite dykes (0.59 m/a). Consequently new steps in the longitudinal profile were formed. Furthermore a structure indicating a recent collapse of an amphibolite dyke which was crossing the river further down stream from the erosion sites was observed in the field (year 1999). This collapse might have been caused by a big flood event such like the Demoina flood in February 1984. For the study river with a basin area of 42 km^2 the averaged 30 years rate of incision equals 0.68 m/a with local maxima of up to 1 m/a which is close to catastrophic. So recent gully erosion processes are influenced by very high river dynamics and controlled by ancient tectonic structures.

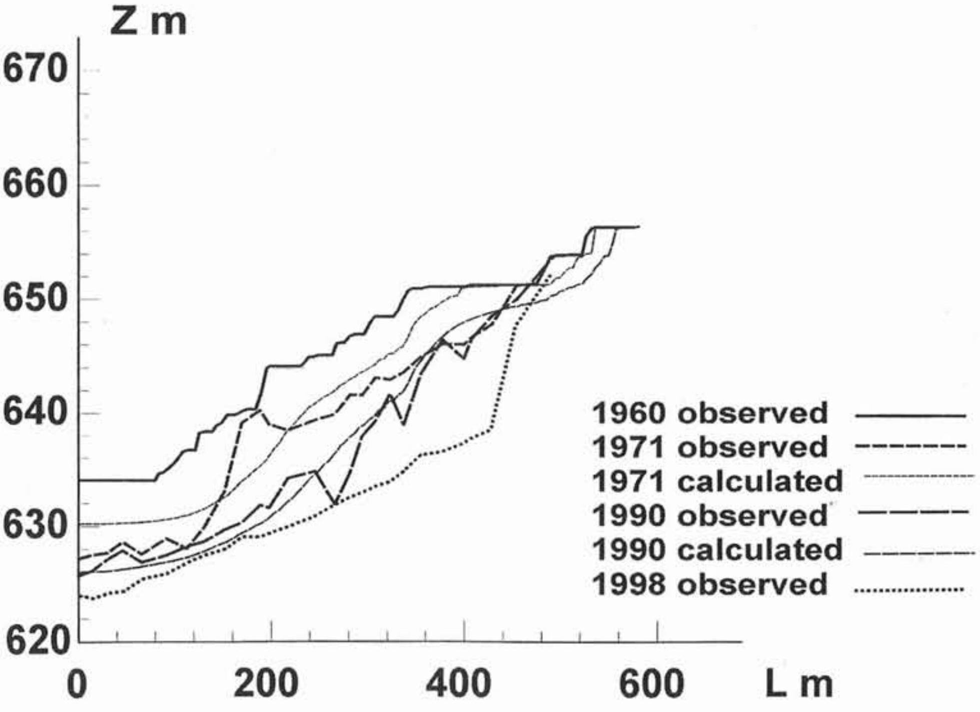

FIG. 5 - Evolution of longitudinal profile of the Mbothoma new gully after observations in 1960-1998.

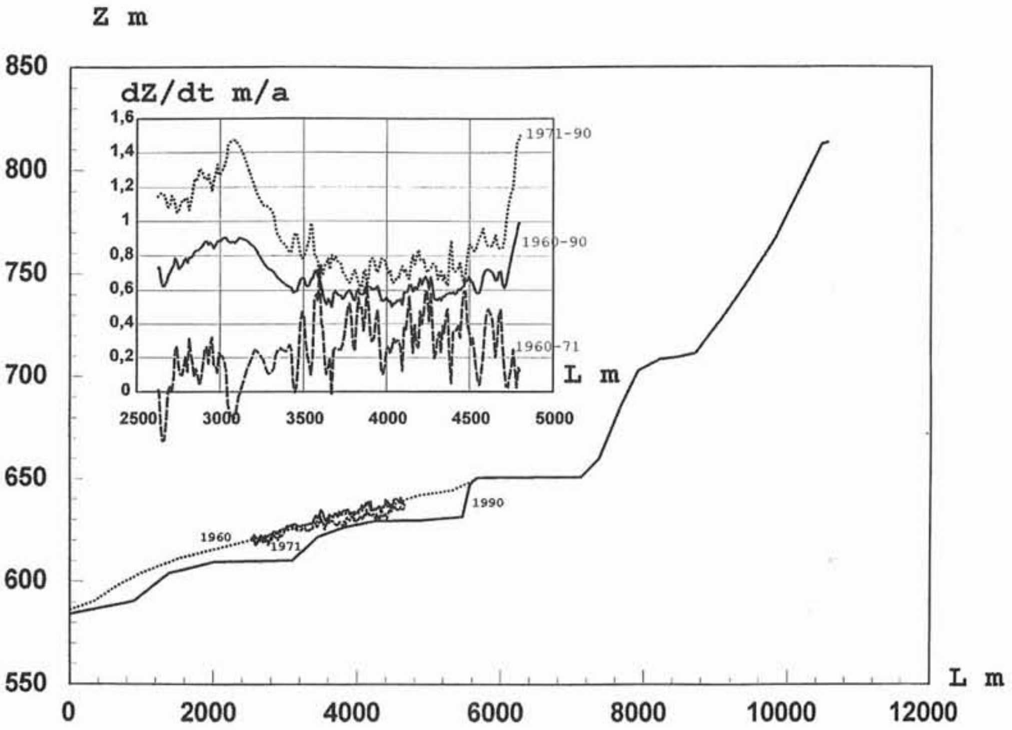

FIG. 6 - Step-pool pattern of longitudinal profile of the Mhlambanyoni River and its dynamics from 1960 to 1990.

The longitudinal profiles, and gully depth, bottom and top width were calculated for the basin of the Mbothoma new gully for all the flowlines over 100 m long. For the period 1960-1995 the water discharges calculated from relevant meteorological data were used. For the successive 135 years a sequence of daily water discharges was simulated on the base of 1945-1995 data. The elevation of the erosion basis (mouth of the gully respectively the bed of the Mhlambanyoni river channel) decrease exponentially during this 150 year period from 633.7 to 615.8 m (fig. 7), with a rapid incision at the beginning of the calculation period and nearly stabilisation of the rived bed at its end.

The calculated elevations of the basin surface were added to the basin DEM (fig. 8). The simulated Mbothoma_new gully system in the year 2110 will have a dendritic pattern, with a main trunk about 1200 m long, and three main dendritic tributaries of 270-560 m in length. The maximum gully length (about 1200 m) is calculated to be more than 95% of the gully catchment length along this flowline. 35% of the entire contribution area will be affected by gully incision in the final situation. The tributaries and the main gully will be up to 15 m deep in their central sections and will have a trapezoidal cross-sections with flat bottoms of 25-30 m widths and steep (more than 45°) side walls. The main trunk of the gully will overlap the existing Mbothoma new gully (1998). The most extensive erosion will occur at the upper part of the basin above the existing gully head. The volume of the gully system was calculated to 1,040,000 m^3 for the gully catchment and the surrounding area (total area 705543 m^2), the layer of erosion will be 4.15 m. The dynamic of gully growth is characterized by a rapid growth rate of gully's maximum length (table 2), followed by gully area, gully mean depth and at last the growth rate of gully volume. This dynamic of gully's morphology evolution is qualitatively the same, as in the experiment of Kosov & *alii* (1978).

TABLE 2 - Evolution of the main morphological characteristics of Mbothoma new gully, calculated with the dynamic gully model

year	Gully volume, m^3	Gully area, m^2	Gully mean depth, m	Gully maximum length, m
1990	239,403	145,543	1,64	950
2000	307,316	161,094	1,91	1026
2010	343,046	167,225	2,05	1026
2020	391,956	175,317	2,24	1026
2030	524,336	195,343	2,68	1032
2040	575,471	202,146	2,85	1032
2050	653,656	212,007	3,08	1038
2060	686,167	215,617	3,18	1038
2070	737,561	221,388	3,33	1038
2080	860,991	234,042	3,68	1038
2090	912,811	238,892	3,82	1042
2100	1,000,000	247,272	4,05	1042
2110	1,040,000	250,025	4,15	1042

The erosion rates of the gully model have been further compared with rough USLE calculations for the same area which does not take into account gully erosion. Thus, to get an idea of the range of erosion rates and of differ-

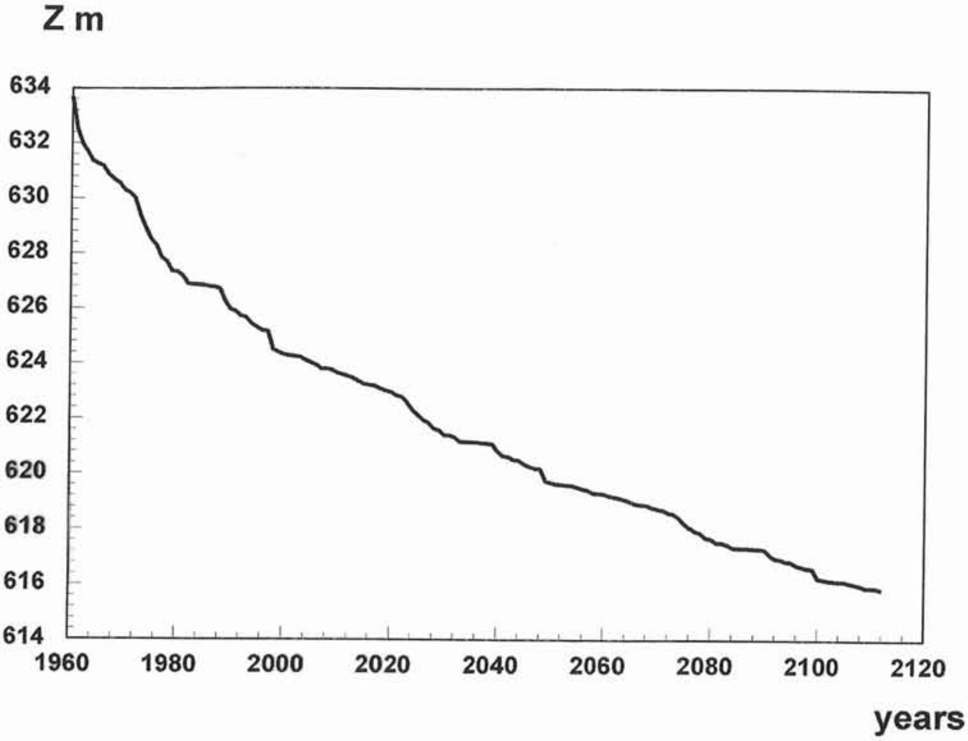

FIG. 7 - Calculated lowering of the erosion base level at the mouth of the gully (the bed of the Mhlambanyoni river channel) during 150 year period.

ences of the specific erosion processes. Therefore the interrill-rill erosion was estimated with the revised USLE (Renard & *alii*, 1991) on a 25x25m pixel base and the single pixel values have then be completely routed down the river network. This implies that sedimentation was neglected. The approximated results of the USLE calculation was 1434 t per year (32 t/ha y) (see Märker & *alii*, 2001b). The averaged soil loss of the estimated entire gully lifespan (150 years) was calculated with a soil density of 1,2g/cm^3 to 8320 tons per year (185 t/ha y).

DISCUSSION AND CONCLUSIONS

The distribution of gully erosion in the study area clearly shows that gully erosion must be included in the calculation of sediment yield, especially where the lithology is highly vulnerable to erosion (saprolites). Nevertheless in traditional models such as the USLE gully erosion is almost completely neglected.

The 1D dynamic gully model describes the evolution of gully's morphology through time based on the system of flowlines initially using a 2D DEM. The complex processes of the interaction between flow and soil cohesiveness in the gully is performed in the model with a rather simple transport equation for bed elevations Z for the condition of pure erosion process:

$$\frac{\partial Z}{\partial t} - kg\rho q \frac{\partial Z}{\partial x} = 0.$$

This equation takes into account the feedback phenomenon of the relief transformation on the erosion rate and it works with a rather limited number of input characteristics: initial longitudinal profile for each flowline; specific water discharge distribution along this line; erosion coefficient k and associated critical velocity of erosion initiation U_{cr} for each soil texture. Initial longitudinal profile along the flowline affects the rate of gully incision and the shape of the gully profile at the beginning stage of gully evolution. After a certain period of gully incision the shape of its longitudinal profile becomes independent from the shape of the initial slope and gully evolution is only controlled by discharge and soil texture: the gully becomes a self-organising feature.

Erosion coefficient and the magnitude of the water discharge effects mainly the rate of gully incision. The critical velocity of erosion initiation and water discharge distribution along the flowlines determine the shape of the gully bed. The critical velocity of erosion initiation of the topsoil layer also controls the gully length. These characteristics must be carefully calibrated with a set of experiments, or with backward calculations using existing information about gully longitudinal profile evolution in similar conditions.

The validation of the dynamic model is difficult due to the small number of studies carried out regarding gully erosion process dynamics. WMS Associates (1988) established from aerial stereo photographs gully erosion rates for the period 1947-1987. The maximum growth rates of 10 m/ y are corresponding to the simulated growth rates.

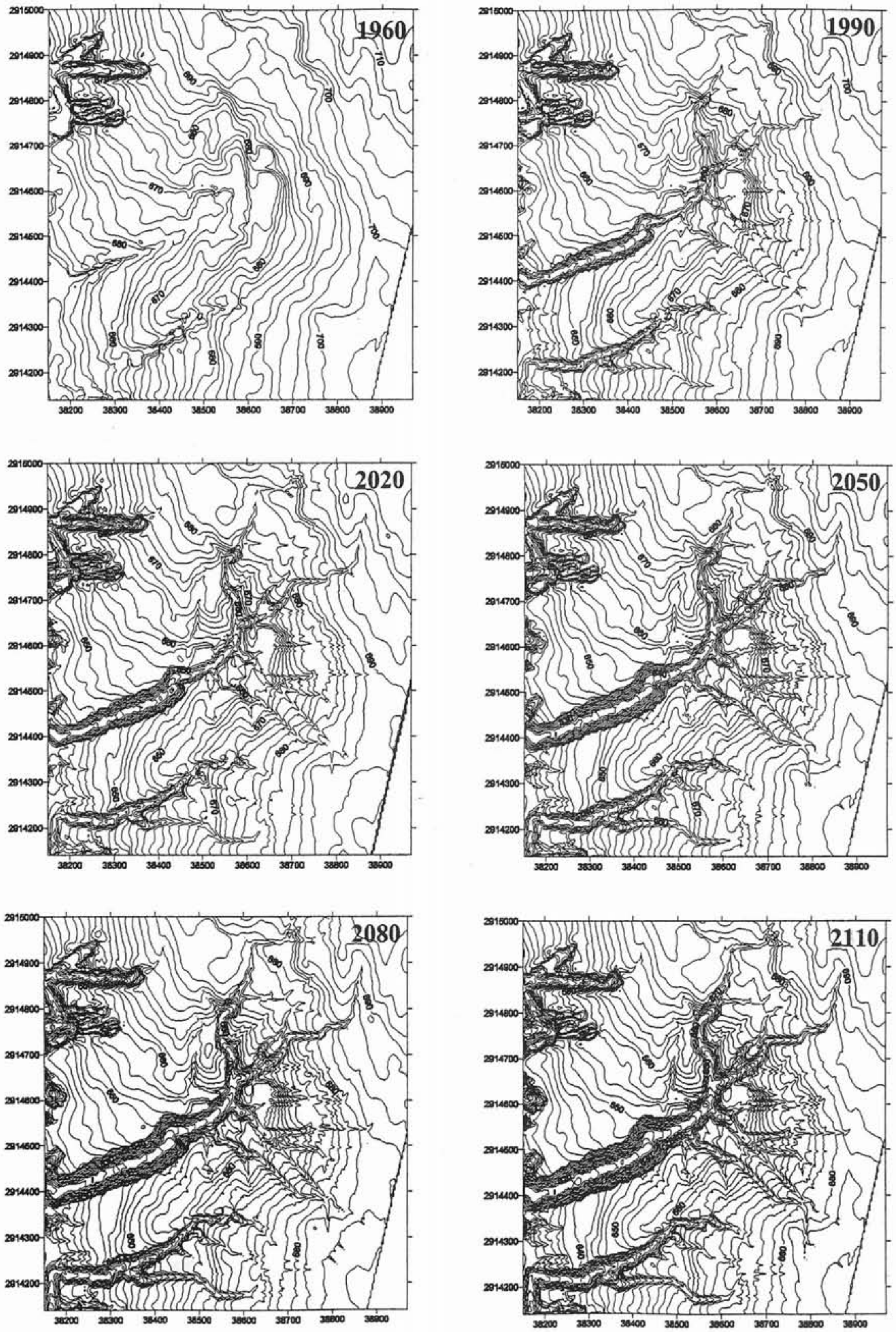

FIG. 8 - Digital elevation models of the calculated surfaces of the Mbothoma new gully system in 30 years steps from 1960 to 2110 (contour lines with 2 m distances).

To get a better validation of the model the results were compared with the observed gully morphometry delineated from the stereo aerial photograph series (fig. 5). Generally a good fitting of the simulated (1971, 1990) and the observed longitudinal profiles for these years can be stated. Especially the lower parts of the gully longitudinal profile up to 100 m from the gully mouth show a parallel lowering corresponding to the field observations. Consequently the model is able to describe the dynamic gully development till the present situation and therefore a reliable forecast of gully evolution can be assumed.

The reason for the gully incision since the beginning of the 1970s is the lowering of the erosion base level (Mhlambanyoni River) due to collapses of the crossing amphibolite dykes. These collapses were caused by intense storm events with high energetic inputs into the system like the Demoina cyclone in February 1984. The disposition to gully initiation given by the physiographic characteristic (saprolites) is finally amplified by the anthropogenic activity like overgrazing phenomena.

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