

## 8. Long-term gully and river channel dynamics in Tigray

(Based on Frankl et al., 2011)

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In the Highlands of Northern Ethiopia gully occurrence is linked to poverty-driven unsustainable use of the land in a vulnerable semi-arid and mountainous environment, where intensive rainfall challenges the physical integrity of the landscape. Trends in gully and river channel erosion, and their relation to triggering environmental changes can proffer valuable insights into sustainable development in Northern Ethiopia.

In order to assess the region-wide change in gully and river channel morphology over 140 years, a set of 57 historical photographs taken in Tigray, and clearly displaying gully cross-sections, were precisely repeated from 2006 till 2009. Ninety-two percent of the gully and river sections (n = 38) increased in cross-sectional area during the studied period, after 1975. Two repeatedly photographed catchments of Lake Ashenge (**Fig. 1**) and Atsela (**Fig. 2**) allowed a detailed study of gully development from 1936 until 2009. Repeat photography was also used to study the gully and the gully network at May Mekdan (**Figs. 3 to 7**).

A conceptual hydrogeomorphic model was devised for these catchments and validated for the Northern Ethiopian Highlands (**Fig. 8**). Three major phases can be distinguished in the hydrological regime of the catchments. In the first phase, between 1868 (or earlier) and ca. 1965, the relatively stable channels showed an oversized morphology inherited from a previous period when external forcing in environmental conditions had caused the channels to shape. In the second phase (ca. 1965 – ca. 2000), increased aridity and continued vegetation clearance accelerated the channel dynamics of the gully and river system. The third phase (ca. 2000 – present) started after the large-scale implementation of soil and water conservation measures. In 2009, 23% of the gully and river sections were stabilizing. This paper validates previous research indicating severe land degradation in the second half of the 20<sup>th</sup> century. Additionally, it demonstrates that the recent erosive cycle started around 1965 and, that at the present time, improved land management stabilizes headwater streams.

### Excursion stops

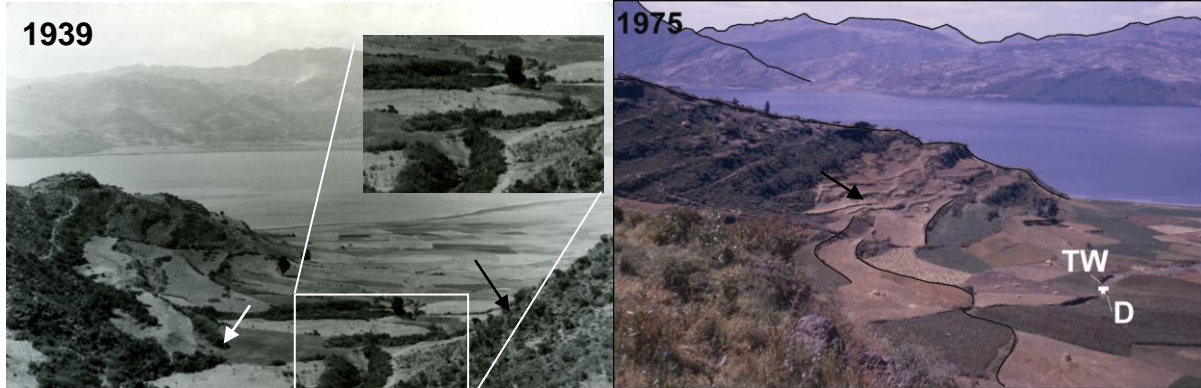
**Stop 1.** Development of a gully in a small catchment draining to Lake Ashenge (p. 40).

**Stop 2.** Panoramic view of the Atsela valley bottom, with Amba Alaje at the back. Here the gully network expanded throughout the 20<sup>th</sup> century and is now shrinking (p. 40).

**Stop 3.** In the field walk around Hagere Selam many gullies will be visited, and particular attention given to headcut retreat around May Ba'ati village (p. 134).

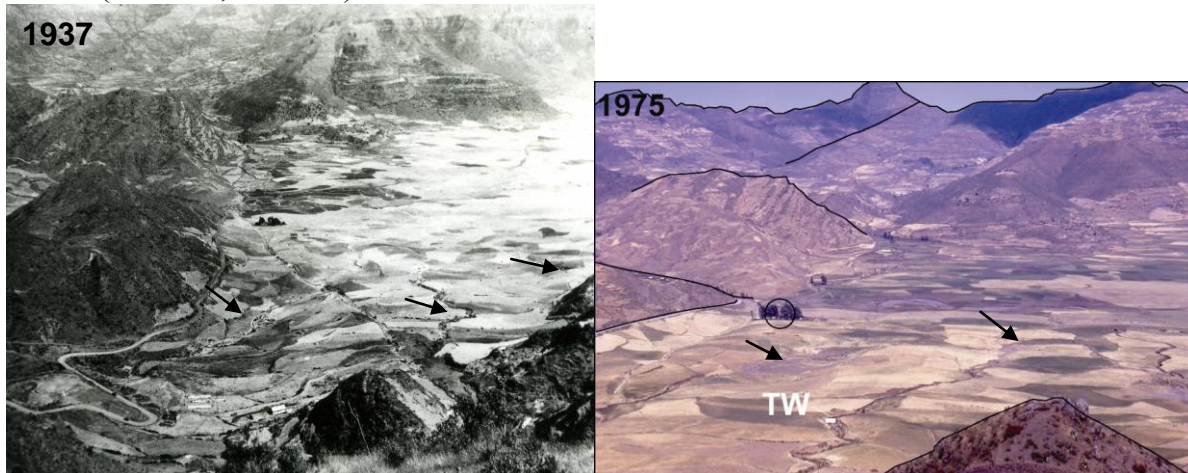
**Stop 4.** At May Makden, the gully will be visited from nearby and its dimensions and characteristics compared to historical photographs (p. 41).

**Lake Ashenge** (12°33'N, 39°31'E)



**Fig. 1.** *Left:* This photograph was taken in 1939 by A. Maugini (© Istituto Agronomico per l'Oltremare, Firenze, I) at Lake Ashenge, shortly after the construction of the road towards Addis Ababa. It shows that wood harvesting and agricultural exploitation severely affected the environment, but that shrub cover on the land (white arrow) and on the surrounding hills (black arrow) remained relatively high. The gully draining the valley is dormant and has been partially converted to cropland (enlargement). By 2009, the gully had extended downstream by 294 m (Frankl et al., 2011). It is now freshly incised and remains active despite the recent soil and water conservation efforts. **Right:** While surveying soil erosion in North Ethiopia in 1975, Neil Munro (Tigray Rural Development Study) incidentally photographed the same valley and gully previously recorded in 1939. The gully in 1975 appears freshly incised. Agricultural expansion was ongoing and is evidenced by recent terracing on the hillside (arrow). Cross-section properties could be calculated using repeat photography (Frankl et al., 2011) and were in 1975: Top Width (TW)= 5.00 m, Depth (D)= 1.73 m. In 2009 TW increased to 11.60 m and D to 3.80 m.

**Atsela** (12°54'N, 39°31'E)



**Fig. 2.** *Left:* First pictured in 1937 by A. Maugini (© Istituto Agronomico per l'Oltremare, Firenze, I), the Atsela catchment was poorly managed and bore the signs of intensive agricultural exploitation. Farmland extended beyond its 2009 area to the lower steep mountain slopes, where terracing was absent. The three gullies (arrows) that nowadays cut through the valley

floor were already present in the early 20<sup>th</sup> century. However, their lower ends were located higher in the valley bottom at approximately 2490 m a.s.l. **Right:** This photograph taken by Neil Munro in 1975 shows that the overuse of the land continued and that the erosive activity of the gullies strongly increased. The channels appear re-incised and prolonged downstream by a total length of 1663 m, ending in large debris cones (arrows). At present, some of the stabilizing gully sections were converted into cropland because risk of flooding is decreased. The Top Width (TW) of the central gully could be calculated (Frankl et al., 2011) and was 6.35 m in 1975. At present the gully TW is 8.20 m (Frankl et al., 2011).

### **May Mekdan** (13°34'N, 39°34'E)

Gullying in the Vertisols around May Mekdan is not recent as old citizens can remember the presence of a gully which could be crossed fairly easy by foot some 50 years ago. Photographs of 1974-1975 (**Fig. 3**), indicate that the gullies in the catchment of May Mekdan were active, having steep walls and carrying coarse bed load. The gully section west of May Mekdan was then some 9.27 m wide and 4.08 m deep (Frankl et al., 2011). Between 1974-1975 and 2009 the gully width and maximum depth doubled. Most of the cross-section change was already accomplished by 1994 (**Fig. 4**), after which the gully incised by a mean of 1.32 m. Despite the implementation of soil and water conservation measures on the hillsides that started in 1995, gullying remains very active (**Fig. 5**), as important flash floods still occur and gully networks expand through piping (**Fig. 6**). First order streams which have a strong link to the surrounding hillsides are de-activating (**Fig. 7**).



**Fig. 3.** The gully west of the town of May Mekdan drains an area of ca. 50 km<sup>2</sup>.



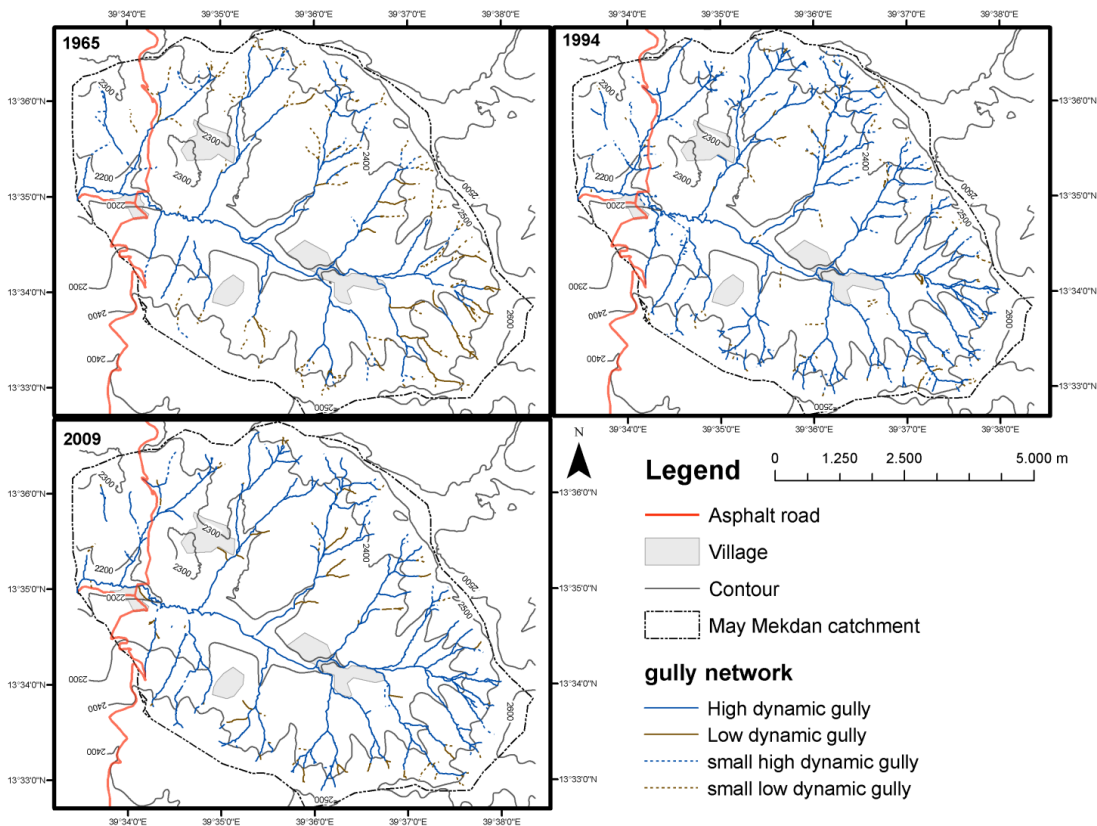
**Fig. 4.** The gap in the gully bank in 1994 indicates the occurrence of large slab failures (arrow). Note the increase in shrub cover after 1994 on the slope in the background.



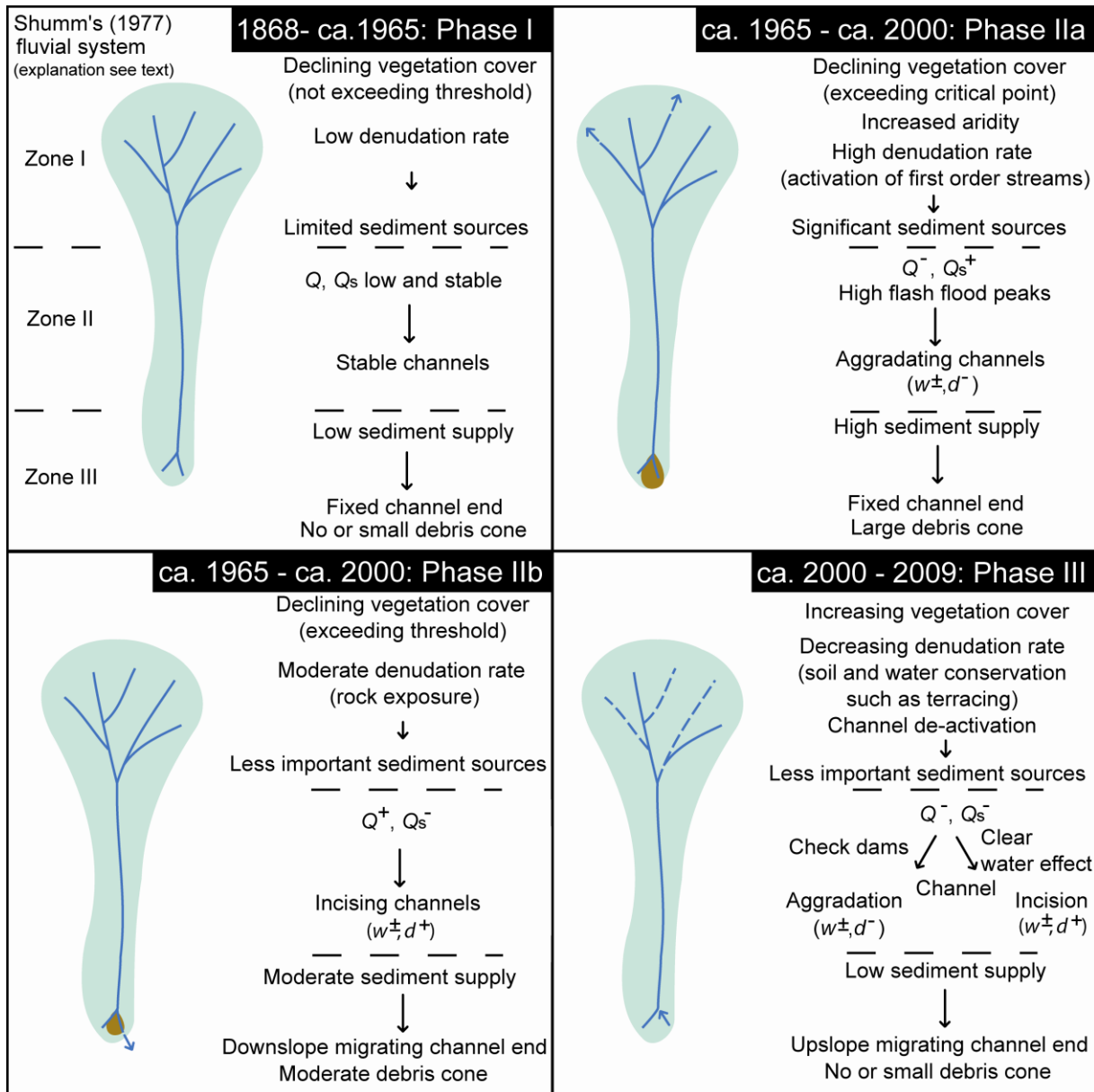
**Fig. 5.** Gully sidewall erosion by a large slab failure was caused by undercutting and the development of tension cracks parallel to the gully wall. Photographs by A. Frankl before (left) and after (right) an important rainfall event in the summer of 2010, when flood marks rose up to 3.5 m in the main gully (Fig. 6).



**Fig. 6.** *Left:* Flood marks were recorded up to a height of 3.5 m in the gully draining the May Mekdan valley, after three successive rainstorms stroke the area in 2010. **Right:** Bank gullies linked to piping in the Vertisols are frequent.



**Fig. 7.** Gully network development between 1965 and 2009 in the May Mekdan catchment (Scholiers, 2009). The area visited during the excursion is located at the lower (western) part of the main gully.



**Fig. 8.** Conceptual model of changes in the hydrogeomorphology of the Northern Ethiopian highlands based on Schumm's (1977) fluvial system. The threshold refers to a critical reduction in vegetation cover resulting in runoff conditions triggering gully incision or network expansion (After Frankl et al., 2011).

## References

- Frankl, A., Nyssen, J., De Dapper, M., Mitiku Haile, Billi, P., Munro, N., Deckers, J., Poesen, J. 2011. Linking long-term gully and river channel dynamics to environmental change using repeat photography (Northern Ethiopia). *Geomorphology*, in press.
- Scholiers, N. 2009. Development of gully networks and volumes since 1965 in the May Mekdan catchment (North Ethiopian highlands). Unpubl. MSc. Thesis. Geography Department, Ghent University, Ghent, Belgium.
- Schumm, S.A., 1977. *The Fluvial System*. John Wiley & Sons, New York.