Urbanization induced changes to the ravine system adjacent to Grand Valley State University

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Student Summer Scholars, 2006

Abstract

Land use practices at Grand Valley State University have dramatically altered runoff, erosion, and slope stability in the ravine system adjacent to campus. Urbanization from campus facilities has resulted in more than 68 hectares of impermeable concrete, asphalt, and buildings. Impermeable acreage, primarily in the form of new parking lots and buildings, increased more than 189% between 1973 and 2004. The increase of impermeable surface area has resulted in decreased lag time, concentrated runoff, and accelerated incision and erosion.

Comparison of 2005 LIDAR topographic data with topographic mapping created in 1963, prior to the construction of the university, reveal consistent degradation in the heads and upper portions of some ravines of as much 4 meters; and aggradation in the lower parts of the ravines of as much as 2 meters. Degradation has created undercut slopes and slope instability, while aggradation has reduced channel slopes, buried riparian vegetation, and in some cases caused lateral erosion and slope instability.

Four continuous-recording stream gages, installed in the ravines, provide hydrograph data for the summer of 2006. Runoff data, combined with continuous precipitation data, provide lag time estimates for storm runoff. Recent erosion and overbank flooding was observed and documented after a storm event on July 17th. Lag times during this event ranged from 10 to 25 minutes. The primary storm drain in the Little Mac ravine (Sauron) contributes 50% of the total discharge measured below all of the stormwater inputs. Only 25% of the flow measured in the Little Mac ravine can be attributed to natural runoff and accretion processes.

Early attempts to control erosion, through the installation of engineered erosion control structures, have been largely unsuccessful and in some cases have contributed to more lateral erosion and slope instability. Check dams intended to reduce erosion have transferred the erosion to the valley walls resulting in increased slope instability in some areas. Dispersal, rather than concentration, of runoff is likely to provide the best long term solution.

Introduction and Research Questions

The ravines are a beautiful resource which should be protected, as well as a potential hazard to the surrounding infrastructure of the university if not carefully managed. The steep hillsides and ravines are currently undergoing rapid erosion, down cutting, and widespread slope instability. It is likely that this erosion is due, at least in part, to an increase in storm water runoff, which is directed to the ravines from impermeable surfaces such as parking lots and walkways.

This study utilized a combination of geographic information system analysis of current and historic data, continuous water level data, and discrete water volume measurements to evaluate the impacts from urbanization at the GVSU Allendale campus. Research questions focused on four main areas:

1. Flow Volume – How does the flow volume directed toward the ravines from GVSU infrastructure compare to what would be expected from a non-urbanized landscape?
2. Erosion – Are short-term and long-term erosion rates in the ravines changing in response to efforts to slow erosion?
3. Slope Stability – What areas of the ravines are prone to slope instability and are these areas related to areas of increased runoff due to storm water discharge to the ravines?
4. Urbanization – How has urbanization increased runoff in the past 43 years?

1. Flow Volume

Pipe discharge measurements were made during a moderate to low flow event. Pipe discharge into the ravines was calculated using flow data measured from each stormwater discharge pipe and some basic math. Relative volume contributions from stormwater pipes are shown in figure 1.

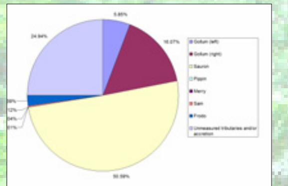

Fig. 1 Pie chart showing the contribution that each stormwater pipe directing water into the Little Mac ravine has to the total discharge at Fangorn (Fig. 3).

Fig. 2 Map showing the locations of the stream gages and a typical stream gage (inset). a) Mordor; b) Fangorn; c) Isengard; d) Shire.

Fig. 3 Map Showing locations of storm drain pipes discharging into Little Mac ravine. a) Gollum [L&R]; b) Sauron; c) Merry & Pippin; d) Frodo; e) Sam; f) Fangorn.

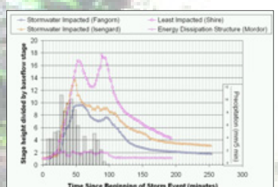

Fig. 4 Combined hydrograph and hyetograph for the July 17, 2006 storm event.

2. Erosion

Infiltration of water underneath the blankets of the boulder armoring has led to unstable conditions of the overlying rock and initiated movement and further erosion during intense storm events (Fig. 6-8).

Channel incision due to increased runoff volume is occurring in many of the ravines (Fig. 5).

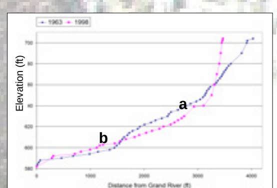

Fig. 5 Stream profiles of the Little Mac ravine using 1963 and 1998 topographic maps. **a)** Erosional area of the ravine, **b)** Aggradational area of the ravine.

Fig. 6 Boulder armoring failure and underlying blanket mobilization in a ravine tributary just south of the Calder Art Center. Photo taken by T. LaCross, 08/01/06.

Fig. 7 Lowest check dam in the Little Mac ravine showing increased erosion due to the stream bypassing it during high flow conditions. Photo taken by P. Womble, 07/20/06.

Fig. 8a Boulder armoring newly installed in the Little Mac ravine. Photo taken by P. Videtich, 09/03/02.

Fig.8 2b Boulder armoring failure in Little Mac ravine. Photo taken by P. Womble, 07/20/06.

Conclusions and Recommendations

- Current measures to control runoff appear to be effective at energy dissipation for short duration, high intensity rainfall events. However, they do not address excess runoff volume.
- Boulder armoring and check dams are failing and, in some cases, increasing erosion. They should not be viewed as a long-term solution to controlling erosion. Ecologically sensitive alternatives, such as the reintroduction of beavers, should to be explored.
- Stormwater detention and runoff volume reduction should be integrated into the design of any changes to the infrastructure on campus.
- Runoff should be directed toward the west part of campus, perhaps into vegetated wetlands, even if this involves some redesign of stormwater pipe grades.
- Vegetated swales should be used to collect, detain, and disperse runoff. Detention structures should allow rapid infiltration and be large enough to handle intense storm events.
- A pilot experiment should be conducted to explore the effectiveness of distributed flow and determine if it is an appropriate stormwater management strategy for GVSU.
- Additional data is needed regarding the flow volume from all stormwater discharge points and the effectiveness of current stormwater detention methods on campus.

Acknowledgements

We'd like thank all those involved, including Matt Camp, Larry Henderson, Edwin Joseph, Leon Palmer, John Weber, Mel Northrup, Kevin Cole, Patrick Colgan, Robert Gould, Jeff Wollett, and Patricia Videtich.

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3. Slope Stability

A slope change map (Fig. 9) was constructed by digitizing the contour lines of a 1963 topographic map and creating a Digital Elevation Model (DEM). Using map algebra, the 1963 DEM was subtracted from a 2005 Lidar DEM. The resulting map highlights areas that have changed.

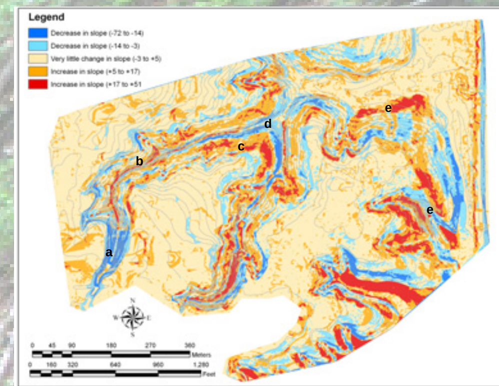

Fig. 9 Slope change map (in degrees) of the Little Mac ravine
a) Zumberge pond fill
b) Steep channel due to incision
c) Unstable, steep slopes
d) Aggredation of sediment
e) Errors in the 1963 topographic map

4. Urbanization

Historic aerial photographs were used to locate impermeable surfaces on campus. In ArcGIS, land-use types were digitized from 1973, 1998, and 2004 aerial photographs. It was assumed that there were no impermeable surfaces in 1963. The area of impermeable surfaces has increased by 189% between 1973 and 2004.

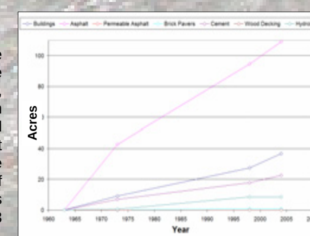

Fig. 10 Impermeable surface increase from 1963 to 2004

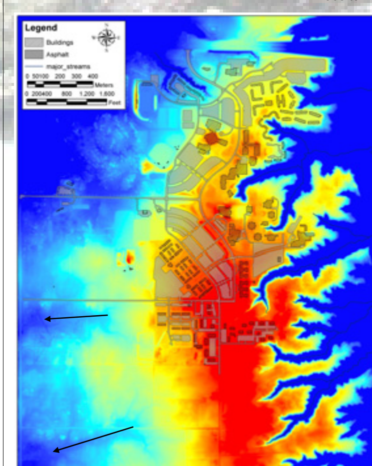

Fig. 11 DEM of the campus showing the location of the drainage divide. Runoff flows away from the high areas (red) to the lower areas (blue) toward the east and west. Of note are the subtle drainages to the west of the divide (marked with arrows) – these could be utilized to direct runoff into detention structures and constructed wetlands.