Urbanization induced changes to a ravine system and evaluation of land use and infrastructure sustainability at Grand Valley State University, Allendale, MI

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ABSTRACT

Land use practices at Grand Valley State University have dramatically altered runoff, erosion, and slope stability in the ravine system adjacent to campus. 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 of urbanization at the GVSU Allendale campus.

Aerial photographs from 1973, 1998, and 2004 were used during the creation of a land use map. 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.

A 189% increase of impermeable surfaces has occurred between 1973 and 2004, an increase from virtually zero acres of impermeable surfaces in 1963 to 168.0 acres in 2004. There was a 160% increase between 1973 and 1998 and an 11% increase between 1998 and 2004. The buildings most at risk for structural damage from erosion are: Kirkpatrick, Copeland, Robinson, Kistler, and Hoobler Living Centers, and Lake Ontario Hall. Recent erosion and overbank flooding was observed and documented after a storm event July 11th. Lag times during this event ranged from 10 to 25 minutes on campus. 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 attributed to natural runoff and accretion processes. The three watersheds with the greatest increase in discharge, based on modeling a 1-inch per hour precipitation event, are number 22, 11, and16. The modeled discharge associated with watershed 22 was comparable to Sand Creek during a low flow period. Undermining of boulder armoring is worst and most damaging on steep slopes such as the slope near the Calder Art Center Saruman discharge pipe.

Stormwater detention and runoff volume reduction should be integrated into the design of any future changes to the infrastructure on campus. More runoff should be directed toward the west part of campus, perhaps into vegetated wetlands, even if this involves some redesign of stormwater pipe grades. The general practice of concentrating runoff into a few locations then treating it with energy dissipation structures is resulting in numerous failures of engineered structures.

INTRODUCTION

Grand Valley State University (GVSU) has undergone extensive land use changes since its founding in 1960. Since its inception, the campus has been a commuter campus located roughly equal distances from Grand Haven, Holland, and Grand Rapids. As the school and its student population have grown, the need for more facilities and room for students has led to conversion of agricultural land to an urbanized landscape. This urbanization has changed the way storm water runs off campus. The effects of increased runoff are most evident in the ravines surrounding the university.

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 of urbanization at the GVSU Allendale campus. A desire to understand the ravine system and the processes of change that are occurring on and around the GVSU campus motivated this study. The lack of data on the ravine system as a whole has hindered efforts to understand and evaluate the impacts of campus urbanization and propose changes that will decrease runoff and reduce impacts to the ravines.

The ravines are a beautiful resource which should be protected; however they are also 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, which can be seen throughout the ravines and is perhaps most prominent just below the newly constructed Lake Ontario Hall, where a large area of slope failure was repaired several years ago just less than 10 meters from the edge of the building.

The erosion in the ravines has been the focus of several class research projects by GVSU faculty members. One faculty member, Dr. John Weber, has done previous studies with students which suggest that the down cutting rate over the past 40 years may be as much as an order of magnitude greater than it was prior to the construction of GVSU (John Weber, personal communication).

Evaluation of current campus infrastructure and stormwater runoff provide valuable insight into what detention structures will be most effective and compatible with existing and future structures.

Background

The basal geologic unit exposed in the study area is a fine, grey clay layer with small sand lenses most likely deposited in a glacial lacustrine environment. Overlying the clay is a fine-grained silty sand layer possibly deposited in a beach environment during the presence of glacial Lake Chicago or an ice-marginal deposit. Glacially deposited till caps the campus area. The sand layer provides an excellent medium for groundwater transportation and storage while the underlying clay layer acts as an aquitard, preventing further percolation. The capping glacial till layer retards infiltration and also acts as an aquitard. Ground water that penetrates the surface till travels along the sand layer and emerges as springs at the sand/lacustrine clay contact in the ravines.

The hydrologic cycle (also known as the water cycle) is the circulation of Earth's water supply (Dunne and Leopold, 1978). When precipitation hits the ground, some water infiltrates into the ground and some runs off. Runoff is the amount of rainfall that moves along the surface of the ground toward water storage areas while infiltration is the amount of water that permeates into the ground to become groundwater. During urbanization, alteration of land cover changes the amount of runoff and infiltration and the hydrological response of the area.

The hydrologic characteristics, in the vicinity of GVSU, have undergone three major changes over the last 200 years: pre-settlement, agricultural development and land clearing, and the current urbanization associated with the growth of the GVSU infrastructure. During pre-settlement conditions, slope, vegetation, geologic materials present, antecedent conditions, and the intensity of the rainfall determined the partitioning of water between runoff and infiltration. In a pre-settlement environment, less water runs off due to energy dissipation and evapotranspiration from the trees. Root systems of the vegetation prevent erosion and allow increased infiltration. When the land was converted for agricultural, use vegetation was cleared from the area. The land clearing caused more runoff due to the annual disturbance of the root systems associated with tilling and planting and the lack of mature trees to slow down overland flow. In the modern urbanized setting, impervious surfaces prevent any infiltration, cultivated areas increase the runoff due to the lack of vegetation, and the storm drain infrastructure focuses the water from impervious surfaces into drain pipes that discharge into the ravines.

The concentration of runoff in stormwater drains increases the volume and speed of runoff that arrives at the ravines, resulting in decreased lag times. Lag time is the amount of time between the center of mass of a precipitation event and the peak of a runoff hydrograph associated with it. Hydrographs are a measure of the changes in depth (stage) or flow (discharge) of a stream plotted against time. Lag times vary based on the size and land uses within a watershed. In non-urbanized landscapes, the time it takes between the peak rainfall and peak of the hydrograph will be longer than in an urbanized landscape due to less infiltration, less vegetation to detain water, and a host of other factors.

The rational method is a simplistic runoff model that can be used to estimate the peak runoff (discharge) based on drainage basin characteristics and the rainfall intensity (Dunne and Leopold, 1978). This method assumes that rainfall intensity is the same over the entire area of the watershed. It is also assumed that runoff from each point in the watershed adds to the total discharge in the streams. A coefficient is used in the rational method to account for different surface infiltration rates and the acreage they occupy in the basin. When runoff from the farthest extents of the watershed reaches the stream, the discharge will be the maximum possible for that rainfall intensity.

A Geographic Information System (GIS) was used to calculate runoff for the different land use types on campus using the rational method. A GIS is a powerful computer based tool that was used in this study to evaluate the changes between GVSU past and present. Layers can be created and edited to represent land use from different years, then subtracted using various tools in the program to determine the changes. GIS programs provide a medium for historic photograph interpretation, digitizing surfaces, watershed delineation, map algebra, and mapping all this information accurately.

In this paper, data will be presented which demonstrates that runoff volume and the rate at which runoff is delivered has increased dramatically to the ravines adjacent to GVSU. The data are consistent with runoff models suggesting that increasing urbanization would increase the flow in the ravines. The results argue for a change to the way the infrastructure at GVSU is planned and implemented and increased efforts to detain and delay stormwater runoff.

METHODS

Urbanization

This project focused heavily on the use of GIS and historic aerial photographs to determine the acreage of different surfaces on the GVSU campus. The acreages were then used to predict runoff under different rainfall intensity scenarios using the rational runoff equation.

ArcGIS 9.1 was the primary engine for GIS work and was used to create and edit the surface layers, calculate fields using map algebra, and export data for use in Excel. Due to their ease of use, the editing tools in Canvas X +GIS were also used to digitize topographic lines and smooth/clean up polygons imported from ArcGIS. The more complicated GIS data manipulations were accomplished using the ArcModel tool to lay out the GIS steps prior to generating the final layers.

Aerial photographs from 1973, 1998, and 2004 were used during the creation of the land use polygons. The 1998 photograph came rectified to the Michigan State Plane South coordinate system. The photographs from 1973 and 2004 were then georeferenced to the 1998 photograph using the georeferencing toolbar in ArcGIS. A GVSU 2005 CAD layer was imported into ArcGIS using Autodesk AutoCAD Map 2000 to extract polygons for the 2004 buildings layer. Based on the 2005 CAD layer, building polygons were deleted or modified to represent changes between the different photographs. The other main source for data was a 1998 CAD file from Fishbeck.

Several different landcover surfaces were identified on the photographs including: asphalt, brick pavers, buildings, cement, permeable asphalt, cultivated areas, and woodland areas.

One carbon-14 (C-14) sample was taken of a large log embedded in the base of Little Mac Ravine. C-14 analysis and dating was done by Beta Analytic, Inc. Observations of the sediments were also made to look for anthropogenic material such as plastic and wire to obtain a maximum age of the sediments.

Pipe discharge calculations

Two different methods were used to determine discharge from stormwater pipes. For the first method, the diameter and water depth in the pipe were obtained using a tape measure and the velocity of water coming out of pipe was measured by holding the bulb of a Marsh McBirney FlowMate II (set at 15-second averaging) in the flow. The cross sectional areas were then determined using the measured width of the water, radius of the pipe, and the depth of the water (Fig 1).

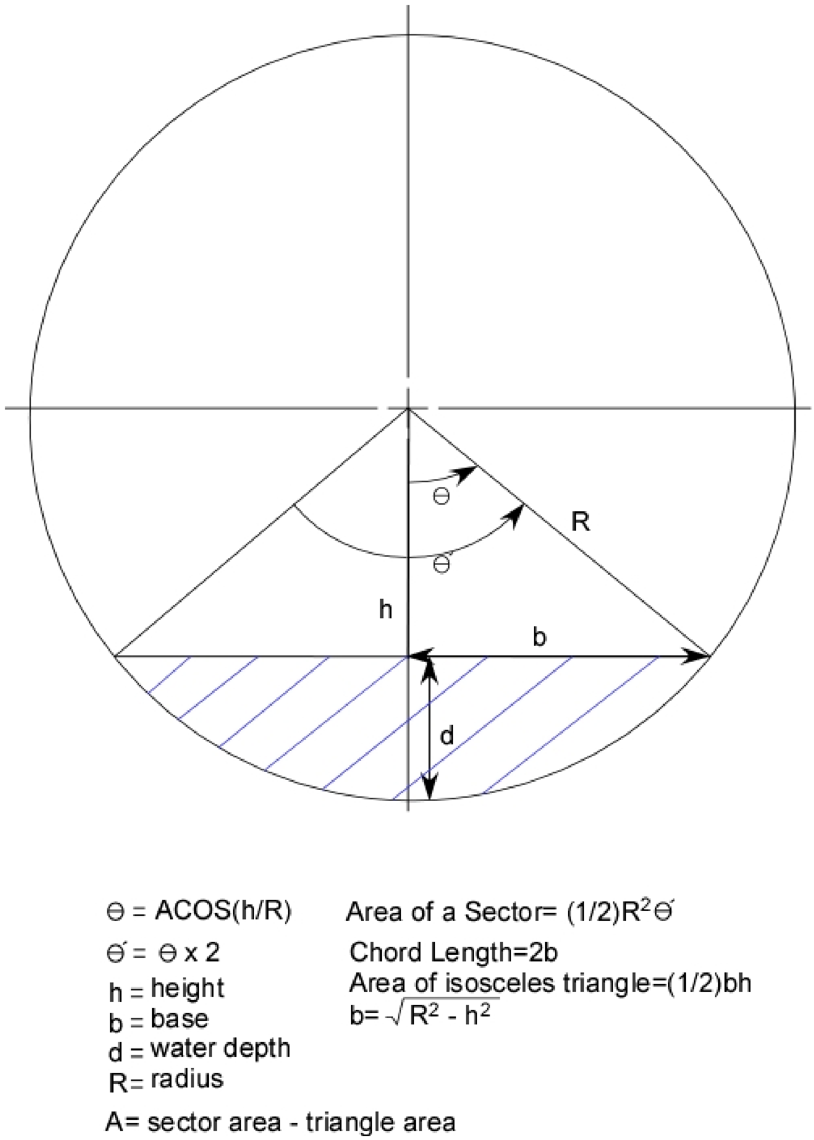


Fig 1 Diagram showing how the area was calculated using the depth and width of the water flowing out of the pipe. This was then converted into cubic into flow by multiplying the area by the velocity to get cubic feet per second.

A second method was used when flow out of the pipe was low and to check the first method for consistency. A section of rubber conveyor belt was used to direct water from the pipe into a 1000mL graduated cylinder (if very low flow) or a five gallon bucket (if high flow). Following collection into the five gallon bucket, water was measured using a graduated cylinder and recorded. The total volume was multiplied by 0.000035315 to convert it into cubic feet then divided by the time it took to fill the graduated cylinder or bucket (Eq 1).

Discharge (cfs) = [volume (mL)* 0.000035315 ft^3] / time (sec)   Eq (1)

Watershed delineation

Light Detection and Ranging (LIDAR) data from 2005 was used to create a raster DEM. A raster dataset from the LIDAR point data was generated using the kriging tool in ArcGIS. Areas with sinks were filled using the FILL tool to decrease errors during the creation of the flow paths. A flow direction map was created using the FLOW_DIR tool for use with the BASIN tool, which delineated the watersheds automatically. This yielded a map that was too general for the small study area. A flow accumulation map was constructed using the FLOW_ACC tool by plugging in the flow direction map to locate the drainage outlets and drainage paths. High flow points were plotted in a new point layer called "pourpoints.shp." To create a more detailed watershed map, the pour point and flow direction layers created previously were plugged into the WATERSHED tool. The resulting map yielded smaller basins around individual ravines, which was better for use in the small study area. The basin and watershed maps were converted into polygons and then combined to provide a good map of the campus ravine watersheds and the rest of the campus property to the west (Fig. 2).

Many small sub basins were formed during the watershed delineation process. Many of these small sub basins were located on the perimeter of the study area and near areas dense with man-made structures such as roads and subdivisions. These small basins were removed of merged with nearby basins. Sixteen basins were used in the final map and were arbitrarily numbered by ArcGIS (Fig. 2).

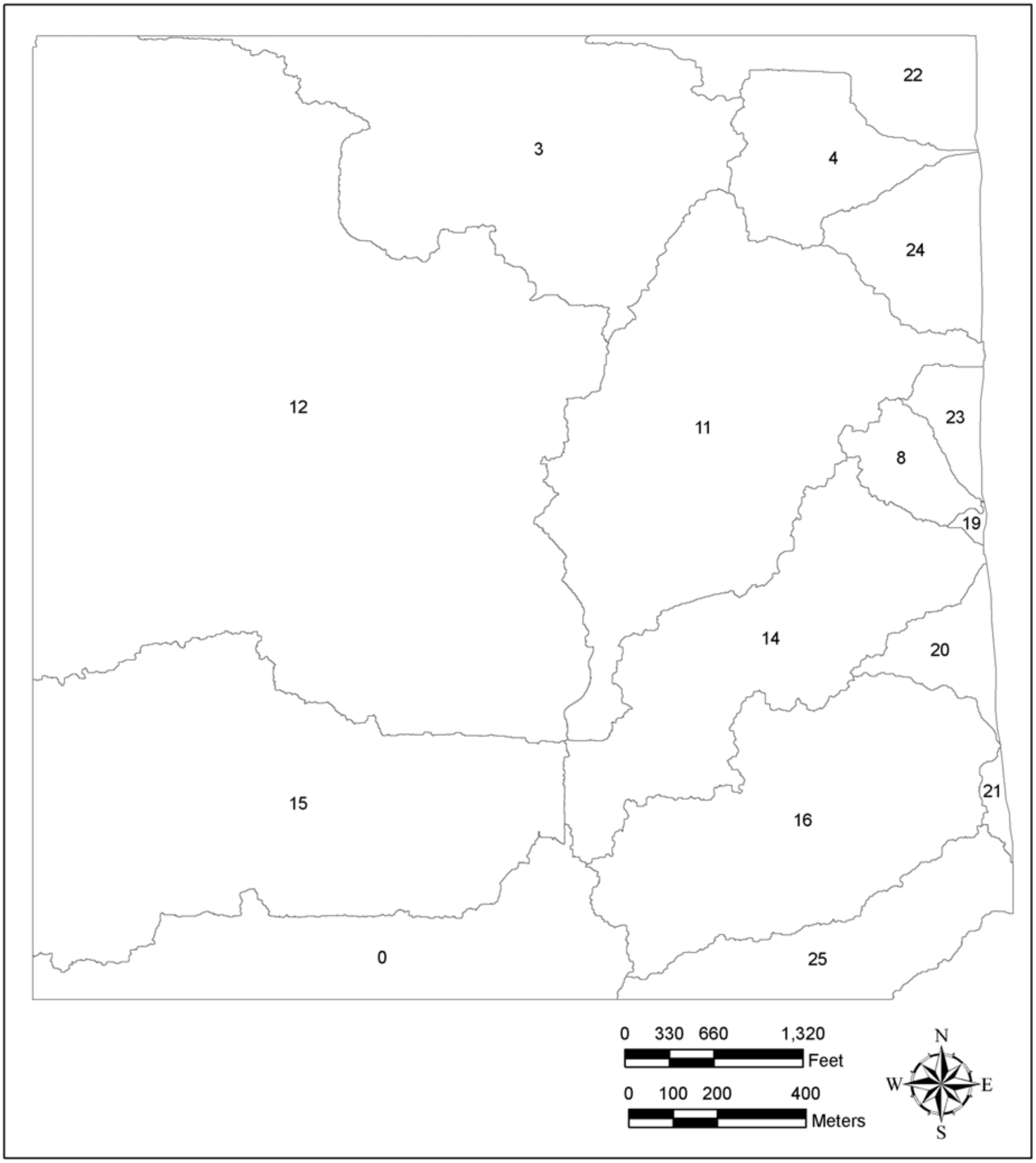


Fig. 2 Final watersheds with label numbers. These numbers are referred to throughout the text.

Rational method for calculating Q_{pk}

The rational method was used to determine peak discharges in each watershed. The areas of each land use type were used in conjunction with runoff coefficients to calculate the peak flow volume for different rainfall intensities. Runoff coefficients were chosen based on Table 10-9 from Dunne and Leopold (1978). The rational runoff equation is given below:

$Q_{pk} = C*I*A$ Eq (2)

with Q_{pk} representing peak discharge (cfs), C the runoff coefficient, I the precipitation intensity (in/hr), and A the area (acres).

Due to the glacial till that covers much of the area of the Allendale campus, the soils are rich in clay and because of this, the c-values given for heavy clay soils were used. The cultivated c-value was used to represent the average coverage of the area surrounding campus which includes surfaces such as: unpaved roadways, wild grasses, lawns, golf course greens and fairways, and small mulched or gardened areas. C-values in the middle of the stated ranges were used (Table 1).

Table 1 Runoff coefficient ranges from Dunne and Leopold (1978) and C values chosen for the study. Note: N/A indicates that the C value was not classified by ASCE in 1978.

Surface	C value range	Chosen C value
Asphalt	0.70-0.95	0.80
Brick Pavers	N/A	0.70
Buildings (Roofs)	0.75-0.95	0.95
Cement	0.80-0.95	0.95
Cultivated	0.50	0.40
Permeable Asphalt	N/A	0.20
Woodland	0.04	0.40

The permeable asphalt was assigned its c-value based on qualitative analysis of its infiltration rate. The infiltration rate information was gathered by pressing an empty coffee can, with the bottom cut off, into some modeling clay to create a seal at the bottom of the can. The can was pushed onto the surface clay side down and then filled with water. The infiltration was compared to material that drained water similarly, such as gravel for the permeable asphalt, and assigned the c-value of that material.

Stormwater allocation to watersheds

Watershed impervious surface drain outlets were traced using a location map of stormwater drains from GVSU Facilities and their outlets and the watersheds delineated previously (Fig 3). Each pipe network was traced to the areas it drained and assigned the number corresponding to what watershed it was located in. For example, if a pipe outlet was located in watershed 11, and a parking lot that fed the outlet was located in watershed 12, the parking lot would be assigned the number 11. A field was added to the attributes table for determining the amount of water that is directed artificially rather than naturally into each watershed and was calculated by adding up all of the peak discharges for each surface based on which watershed they were directed into. This map algebra was done using the DISSOLVE tool in ArcGIS. The stormwater pipe map, however, was not very detailed and had several areas where pipes were not connected to any discharge areas. This introduced errors due to the inability to determine where stormwater was going. Refinements to the stormwater allocation will occur once more accurate information is obtained.

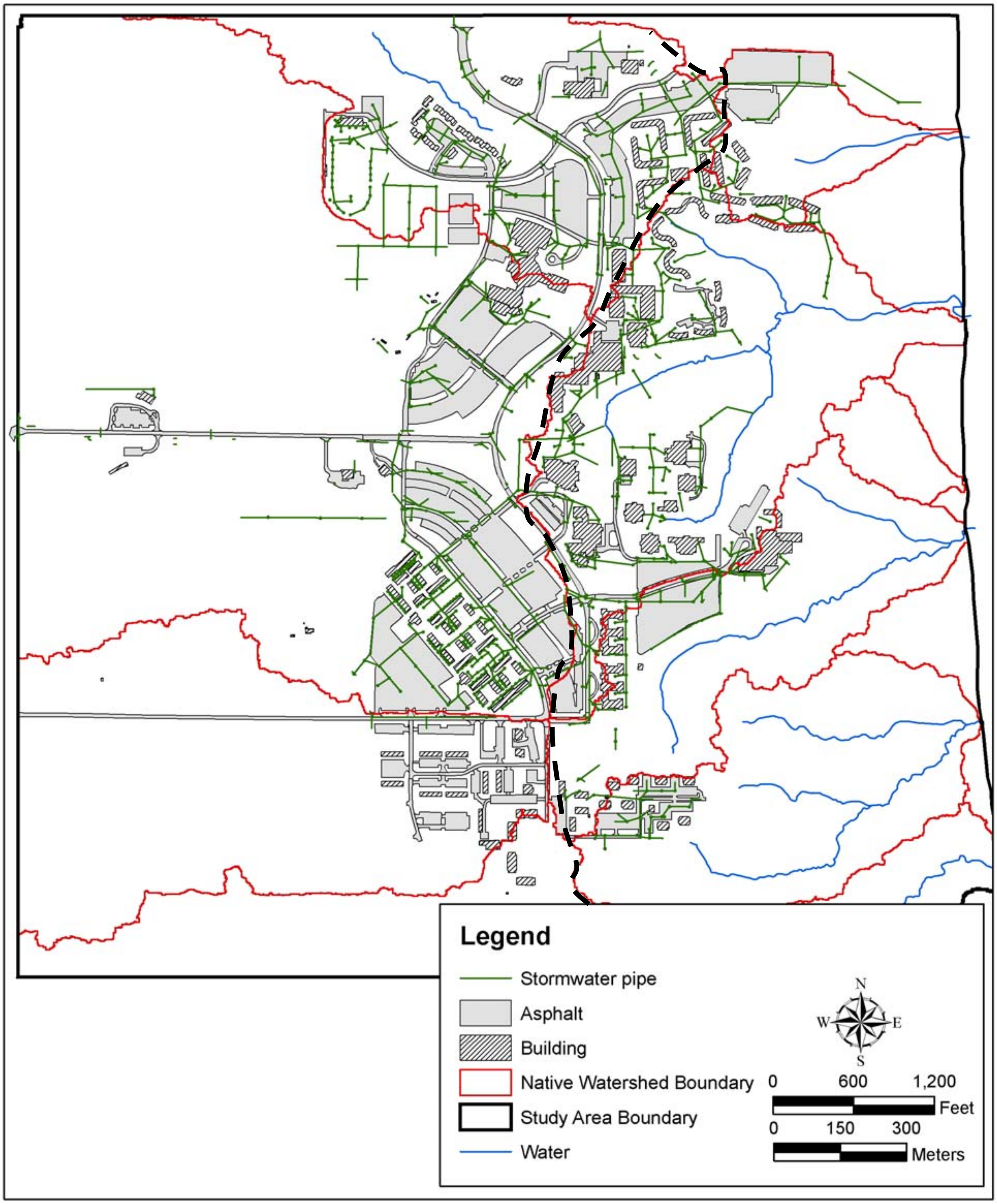


Fig 3 Stormwater pipe locations. The dashed line represents the location of the drainage divide.

Land surface elevation changes using GIS

A portion of Little Mac Ravine was digitized from a 1963 topographic map. Lines were digitized in Canvas X +GIS then imported into ArcGIS for creation of the Digital Elevation Model. The 1963 map was georeferenced using features still present on the modern campus such as Seidman, Zumberge Library, and Lake Michigan Hall. The georeferenced topography lines were edited and assigned the correct elevations and a DEM was constructed. LIDAR was used to create a modern DEM to compare to the 1963 map. The quality of the 1963 topographic mapping was poor in some areas resulting in apparent changes that were in fact created by the mapping accuracy changes. Restricting the area of analysis to the area immediately adjacent to the creek could be more accurate for streambed changes.

Stream gages

Four continuously recording stream gages, installed in the ravines, provide hydrograph data for the summer of 2006. Runoff data, combined with continuous precipitation data obtained from a tipping bucket rain gage on the roof of the commons, provide lag time estimates for storm runoff. Temperature and pressure data loggers were purchased through Dataflow Systems Pty Ltd. A casing was designed and constructed for each sensor to hold it stable and protect it from damage. Each casing consisted of a 4-inch schedule 30 white PVC outer pipe mounted to a fence post or stable object such as a tree trunk or cement containing wall. Inserted into the outer casing was a 1 1/2"- inch white PVC pipe that held the sensor stable at the bottom. Holes were drilled into the sides of the pipes to allow unobstructed water flow.

Locations for each sensor were chosen based on how stable the streambed was, accessibility and visibility to prevent vandalism, and how impacted the ravine was. Gages were placed in three ravines on the GVSU campus: Little Mac ravine, Calder ravine, and the Shire ravine; and one in Sand Creek (Fig. 4). The Little Mac ravine is heavily impacted by urbanization, the Calder ravine is moderately impacted, and the Shire ravine is not impacted. The gage in Sand Creek was installed to provide data from a much larger watershed with longer lag times for comparison.

There were two sensors installed in the Little Mac ravine. One sensor, named Mordor, was installed in a concrete dissipation structure located near the head of the ravine to keep track of the volume of water flowing into it. The location of the second sensor, Fangorn, is near the outlet of the ravine and measures the discharge of nearly the entire ravine, including all of the stormwater pipe inputs. The site is located approximately 800 feet upstream from the Grand River to prevent false readings during a potential flooding event.

Fig 4 Map showing the locations of the stream gages a) Mordor; b) Fangorn; c) Isengard; d) Shire and a typical stream gage (inset).

Modern installed structures

Check dams and the boulder armoring were examined and photographed. These photographs were compared to photographs taken in 2002 and 2003 by Dr. Patrica Videtich of GVSU. The stability and effectiveness was qualitatively analyzed by photographing the change in location of the boulders following major events.

Structure vulnerability

A slope map was created from the LIDAR data using the SLOPE tool. Slopes less than 25° were excluded from the map. A multibuffer was constructed on the 2004 building layer at 25, 50, 75, and 100 foot distances around each building polygon. Buildings that had potential risk to structural integrity were defined as being with 50 feet of a location having a slope greater than 35°.

RESULTS

Urbanization and slope stability

The majority of the impermeable surfaces are located on the eastern half of the study area for all years studied (Fig 5, 6, 7). Overall, there was a 189% increase of impermeable surfaces from 1973 to 2004 (Fig 8 and Table 2). There was a 160% increase between 1973 and 1998 and an 11% increase between 1998 and 2004. Asphalt has been the largest contributor of impermeable surface increase throughout all years. In 2004, asphalt and buildings made up 13% of the 1160 acre study area, or a total of 169 acres.

There are several buildings that could be in danger of losing structural integrity in the future if measures are not taken to secure the slopes below them (Fig 9). The buildings most at risk are: Kirkpatrick, Copeland, Robinson, Kistler, and Hoobler Living Centers, and Lake Ontario Hall. All of these buildings have slopes that are 35°-40° at some point within the 50-foot buffer zone surrounding them.

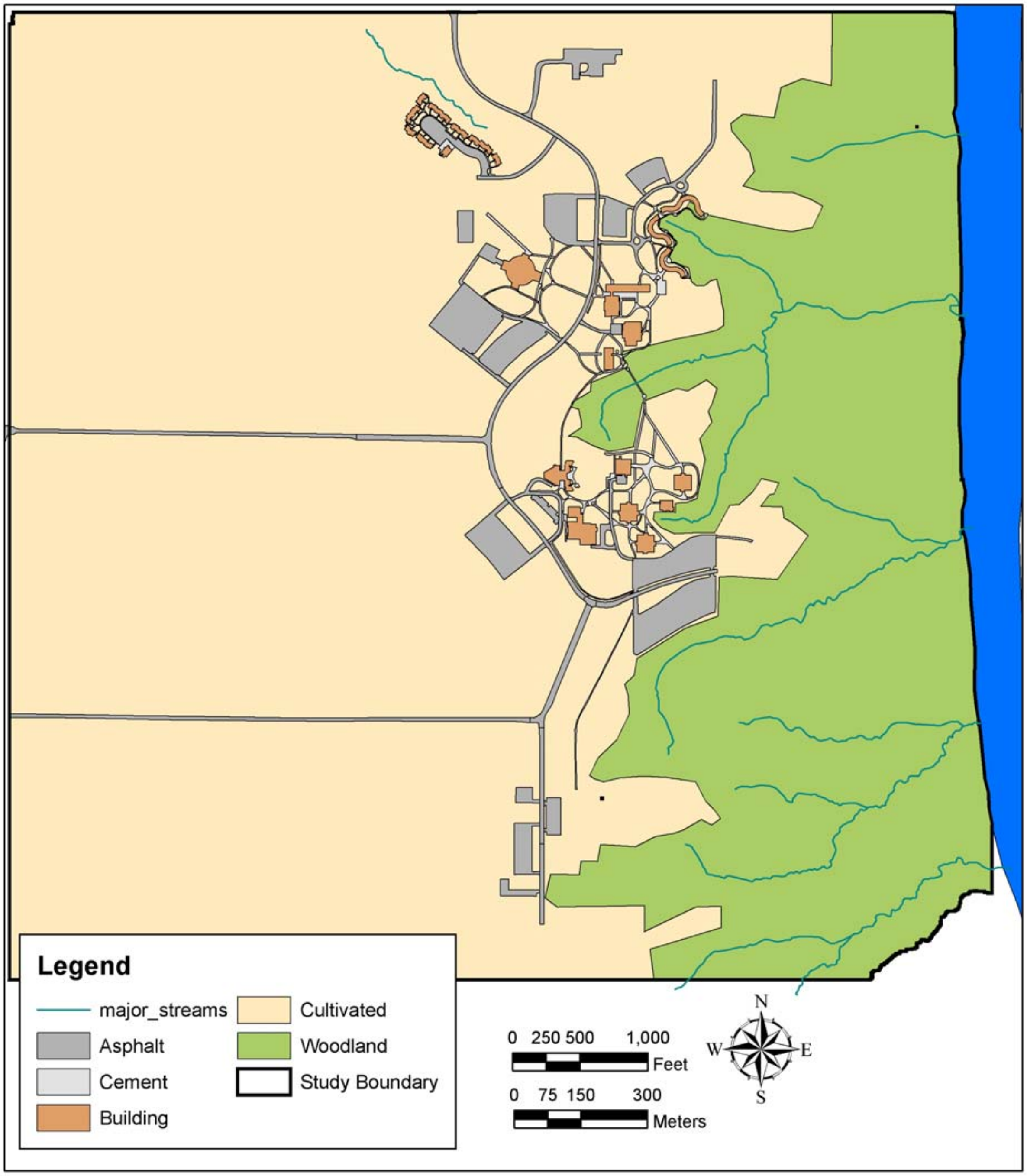


Fig 5 Landuse map of GVSU based on 1973 aerial photography.

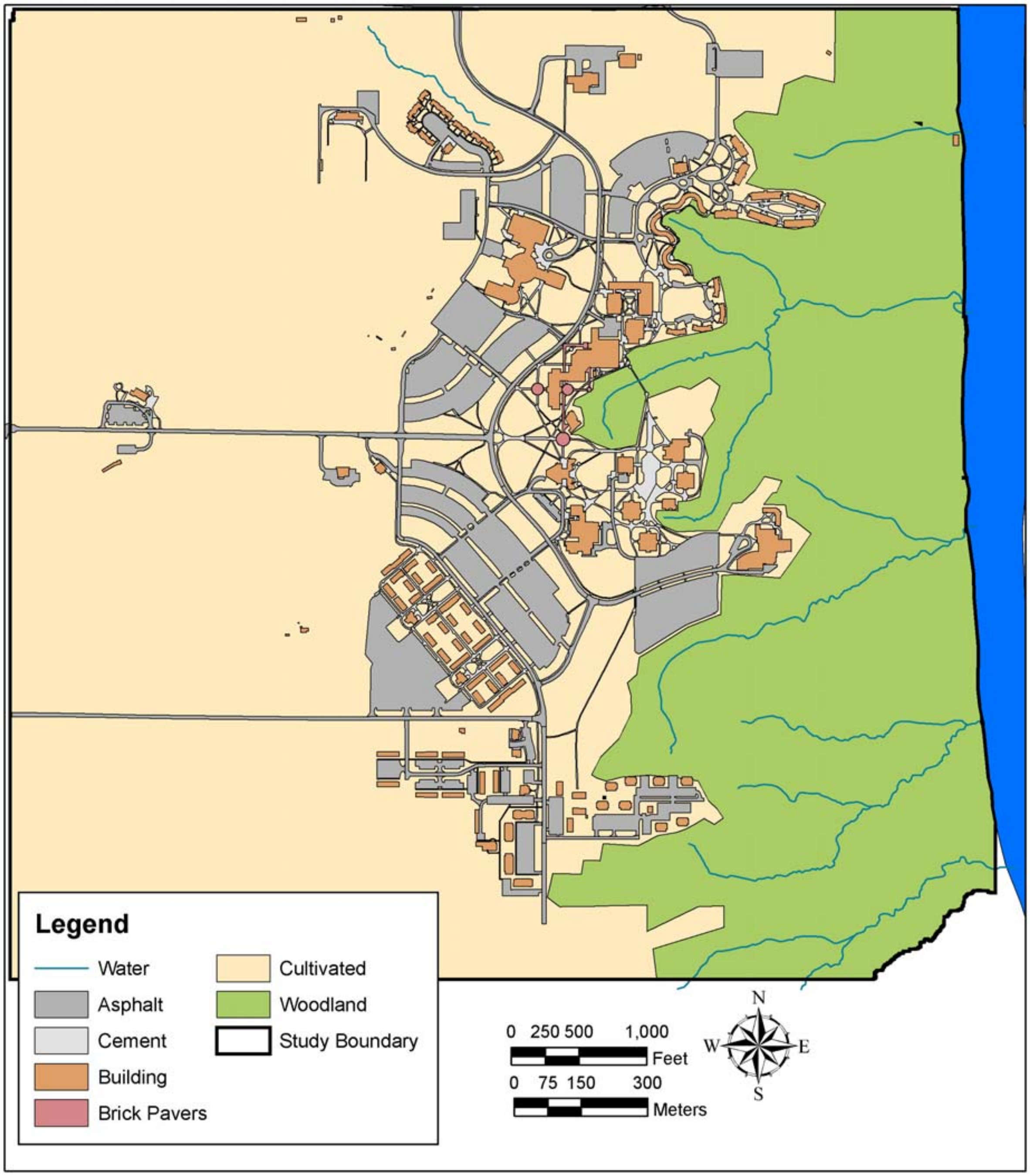


Fig 6 Landuse map of GVSU based on 1998 aerial photography.

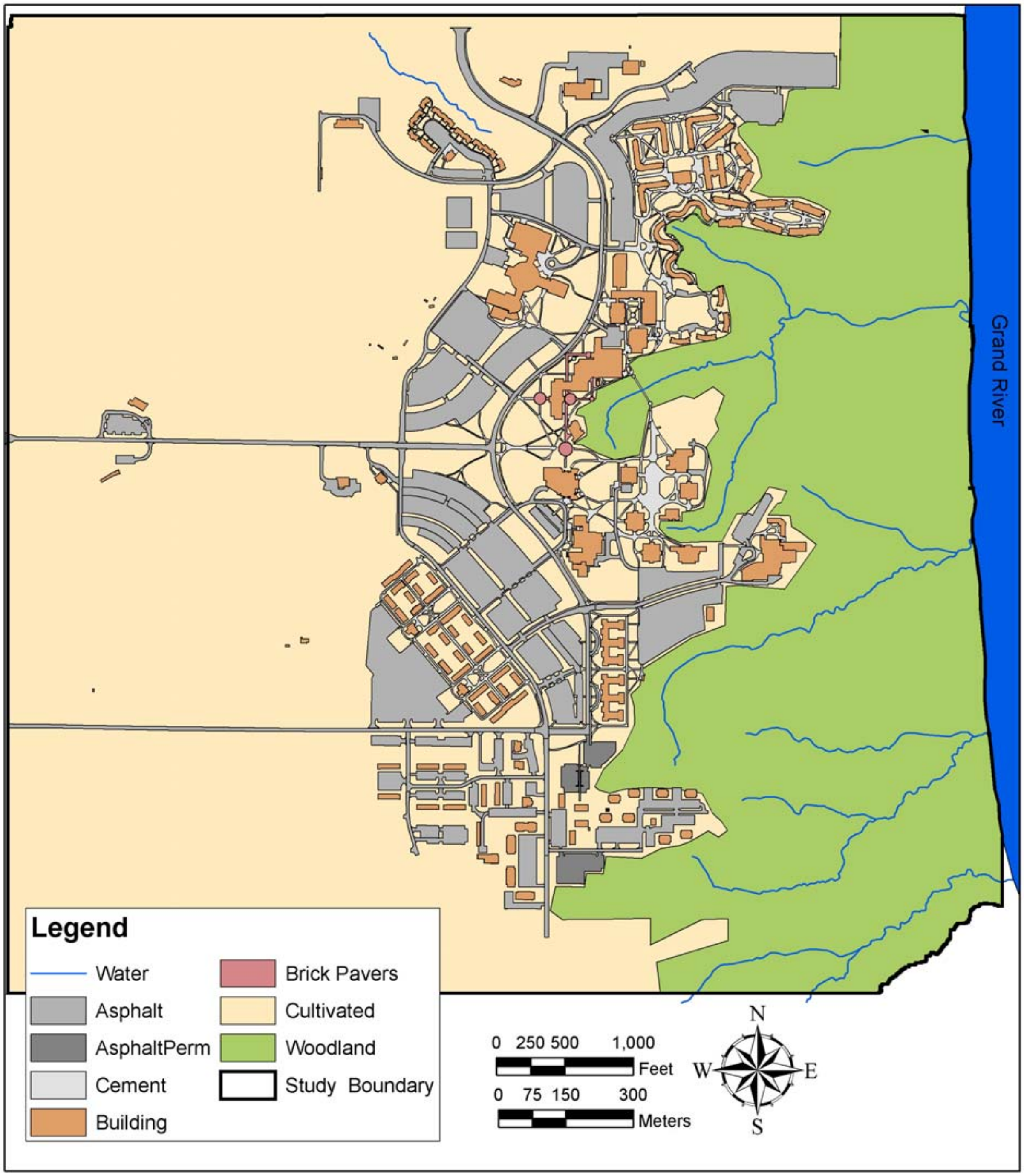


Fig 7 Landuse map of GVSU based on 2004 aerial photography.

Table 2 Impermeable and permeable surface changes between 1963, 1973, 1998, and 2004.

Surface	1963	1973	1998	2004
Buildings	0.0	9.0	27.5	36.6
Asphalt	0.0	42.6	105.0	109.0
Permeable Asphalt	0.0	0.0	0.0	3.2
Brick Pavers	0.0	0.0	0.7	0.9
Cement	0.0	6.9	18.9	22.4
Cultivated	834.3	776.2	691.9	663.9
Woodland	325.3	325.0	325.0	324.6
Total impermeable	0.0	58.5	152.2	168.9
Total permeable	1159.6	1101.2	1016.9	991.7
Percent of total area that is impermeable[1]	0%	5%	13%	15%
Percentage increase of impermeable area	-	-	160%	11%

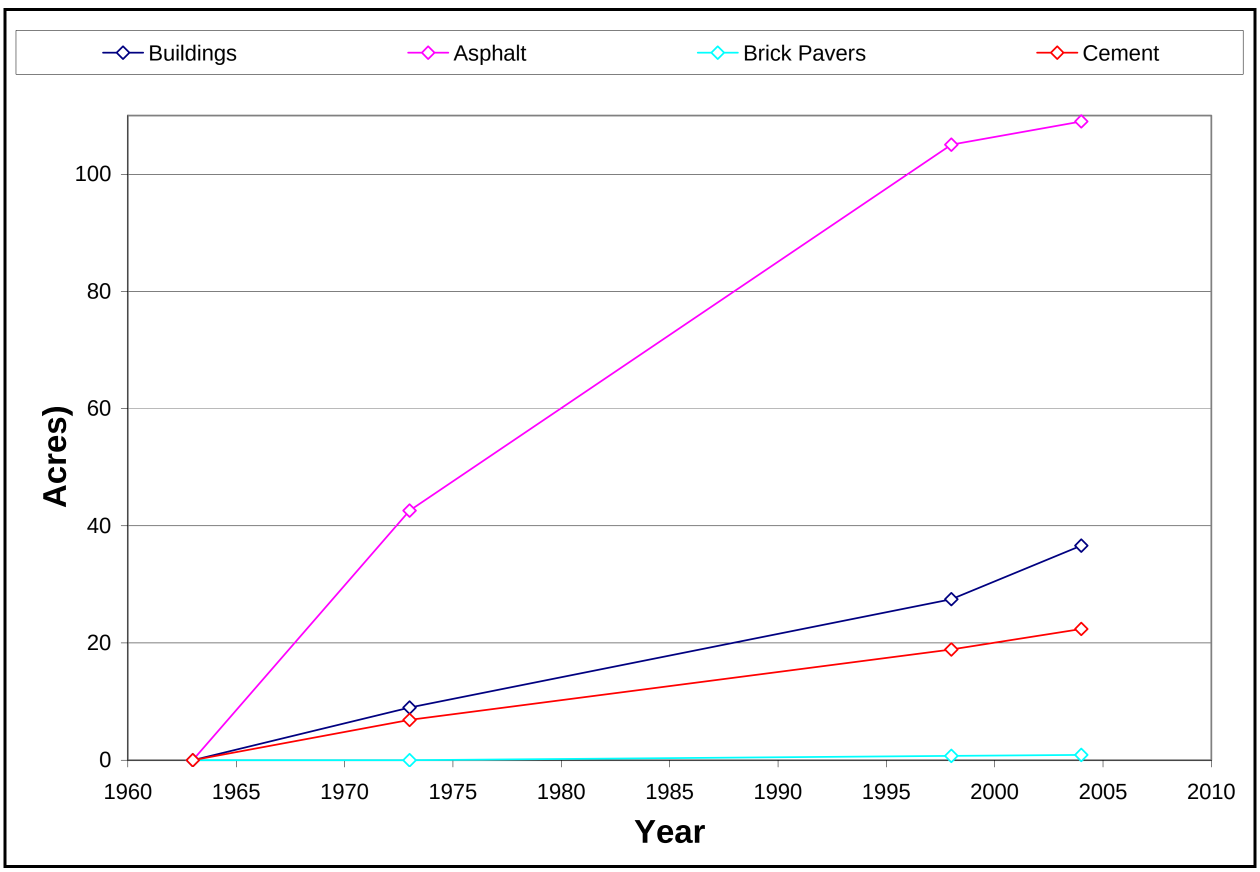


Fig 8 Impermeable surface increase trends from 1963 to 2004.

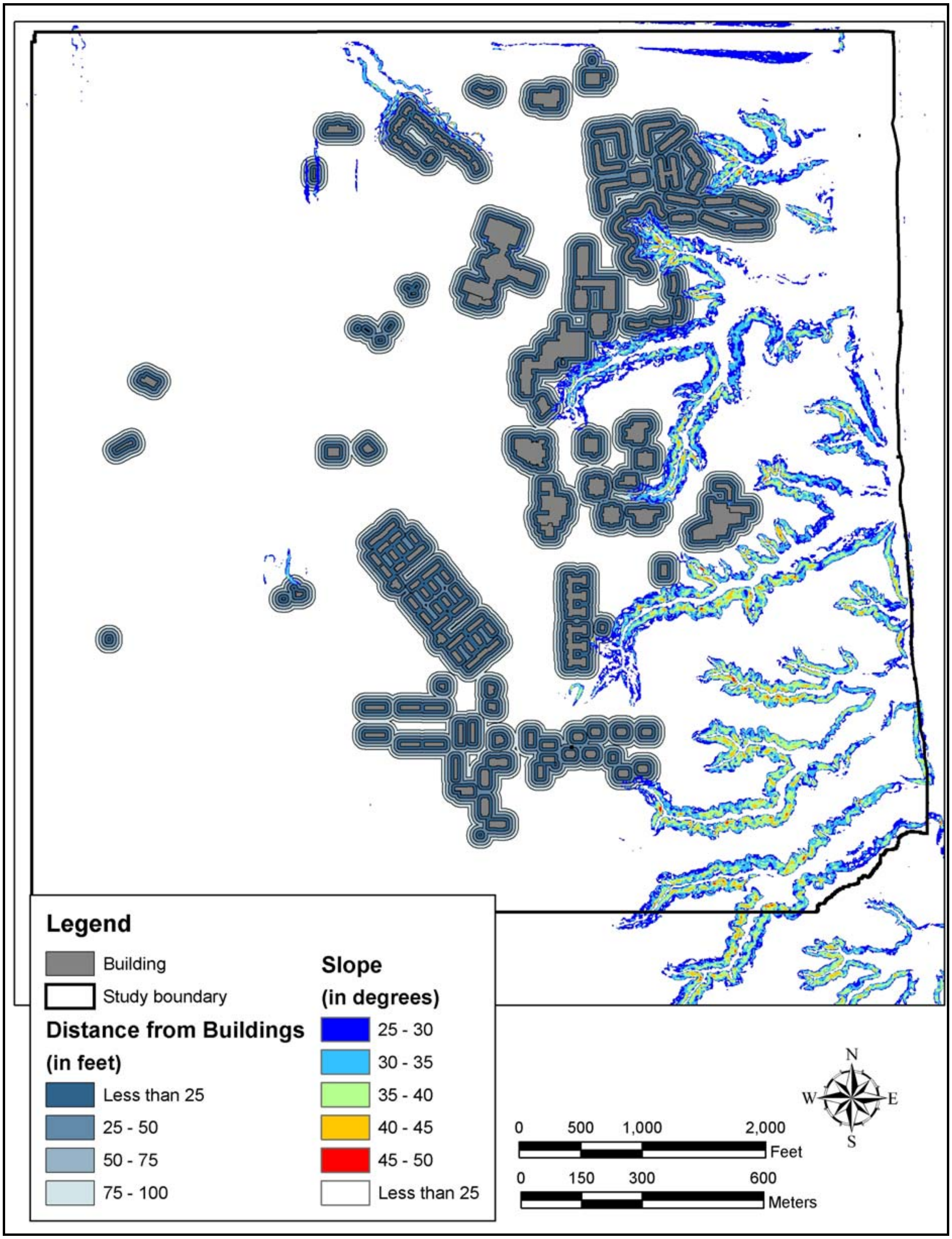


Fig 9 GVSU building proximity to potentially unstable slopes.

Erosion

Channel erosion is prevalent in many of the ravines. The Little Mac ravine was significantly altered during the construction of Zumberge pond near Zumberge Library. Approximately 500 feet at the head of the ravine was filled in and has subsequently steepened the gradient of the stream dramatically (Fig. 10). The two profiles cross at three points: near the head, middle, and end of the ravine. The lowermost point where the two profiles cross is not significant as it may simply signify changes associated with the migration of the stream. The transition from degradation to aggradation occurs at the middle point.

The Little Mac ravine shows distinct areas of aggradation and degradation as well as steepening on the slopes adjacent to the stream (Fig 11). The graph of the stream profiles and the areas of aggradation, degradation, and slope steepening in Figure 12 coincide and show an increase of as much as 2 meters of sediment.

The carbon-14 dating concluded that the wood could be dated somewhere between 1650 and 1950 (Fig 12). The base of the stream at Fangorn is eroding through deposits that were placed there recently.

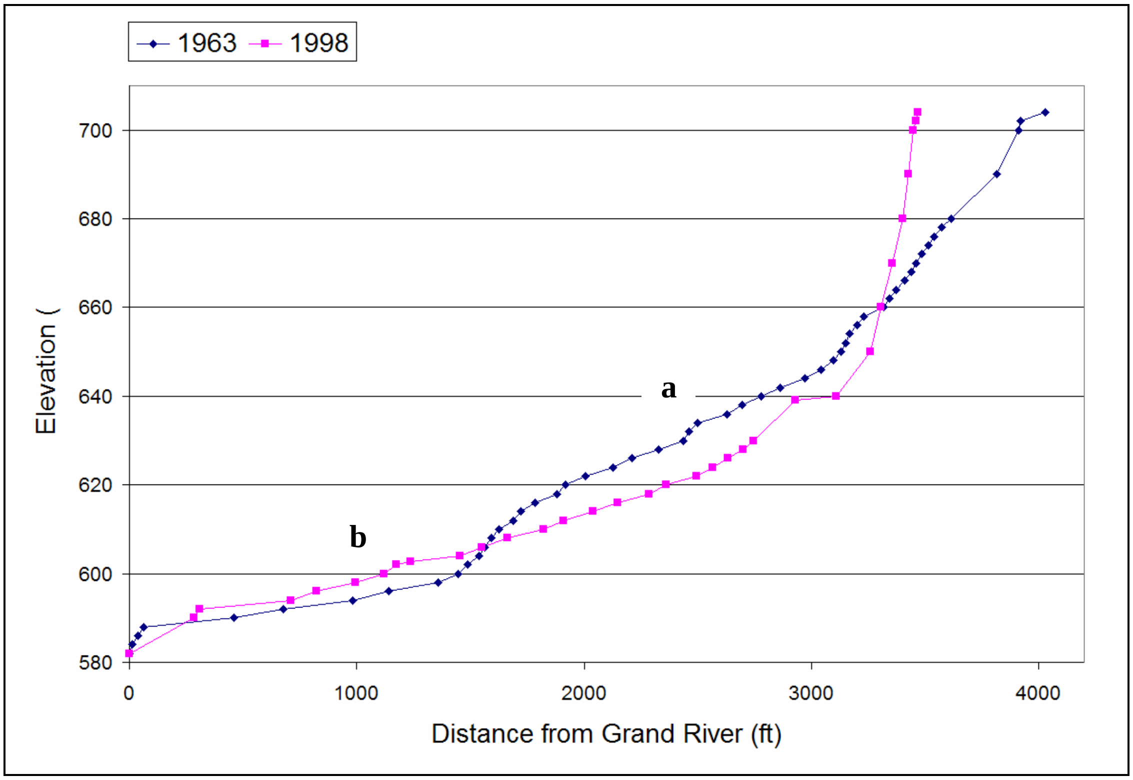


Fig 10 Stream profiles of the Little Mac ravine using 1963 and 1998 topographic maps. **a)** Erosional area of the ravine, **b)** Aggradational area of the ravine.

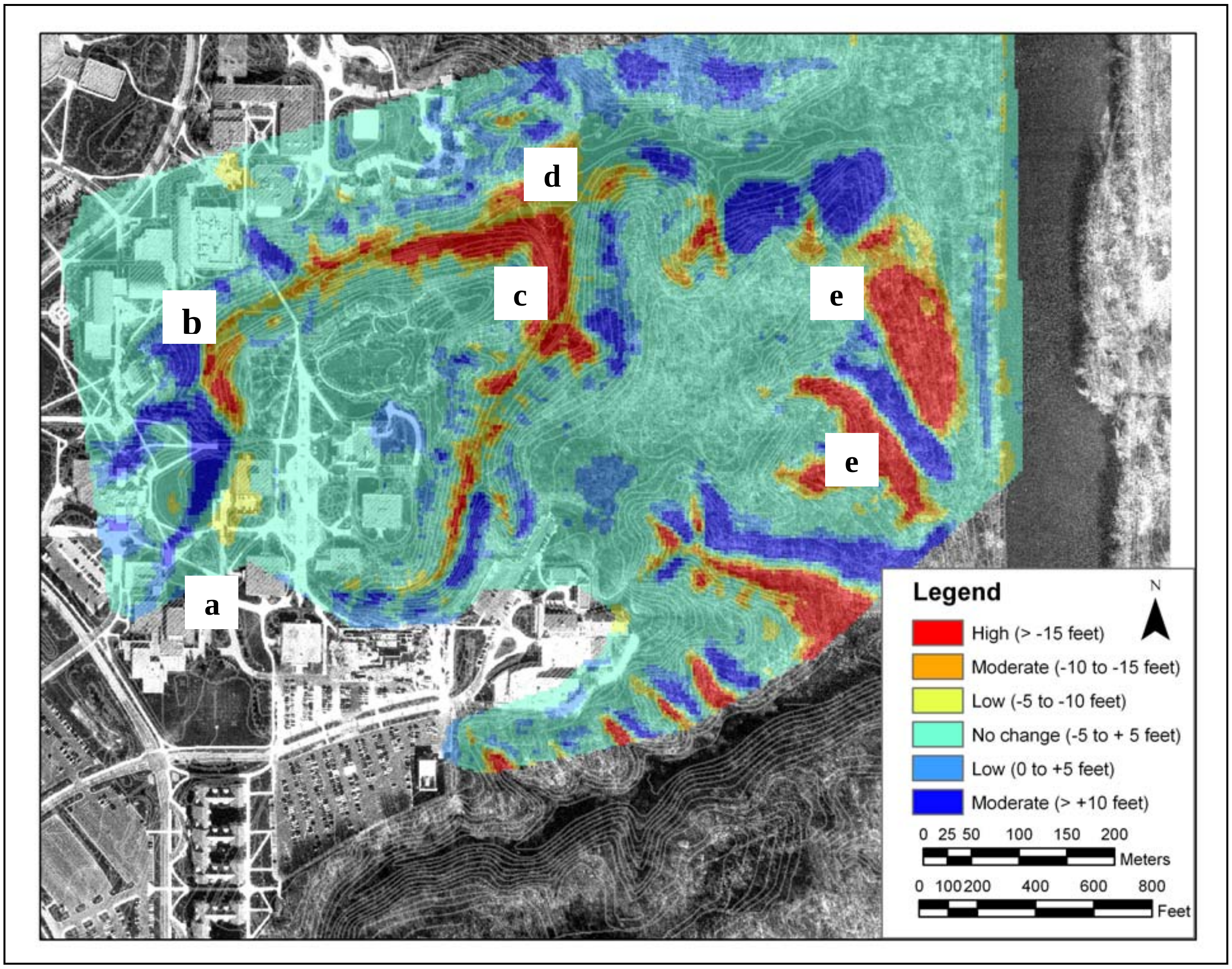


Fig 11 Map of the amount of land surface elevation change of the Little Mac ravine between 1963 and 2005. **a**) Zumberge pond fill **b**) Steep channel due to incision **c**) Unstable, steep slopes **d**) Aggredation of sediment **e**) Errors in the 1963 topographic map

(Variables: C13/C12=-24.8:lab. mult=1)

Laboratory number:	**Beta-217917**
Conventional radiocarbon age:	**180±40 BP**
2 Sigma calibrated results: (95% probability)	**Cal AD 1650 to 1710 (Cal BP 300 to 240) and Cal AD 1720 to 1880 (Cal BP 230 to 70) and Cal AD 1910 to 1950 (Cal BP 40 to 0)**

Intercept data

Intercepts of radiocarbon age with calibration curve:	Cal AD 1670 (Cal BP 280) and Cal AD 1770 (Cal BP 180) and Cal AD 1800 (Cal BP 150) and Cal AD 1940 (Cal BP 10) and Cal AD 1950 (Cal BP 0)
1 Sigma calibrated results: (68% probability)	Cal AD 1660 to 1680 (Cal BP 290 to 260) and Cal AD 1730 to 1810 (Cal BP 220 to 140) and Cal AD 1930 to 1950 (Cal BP 20 to 0)

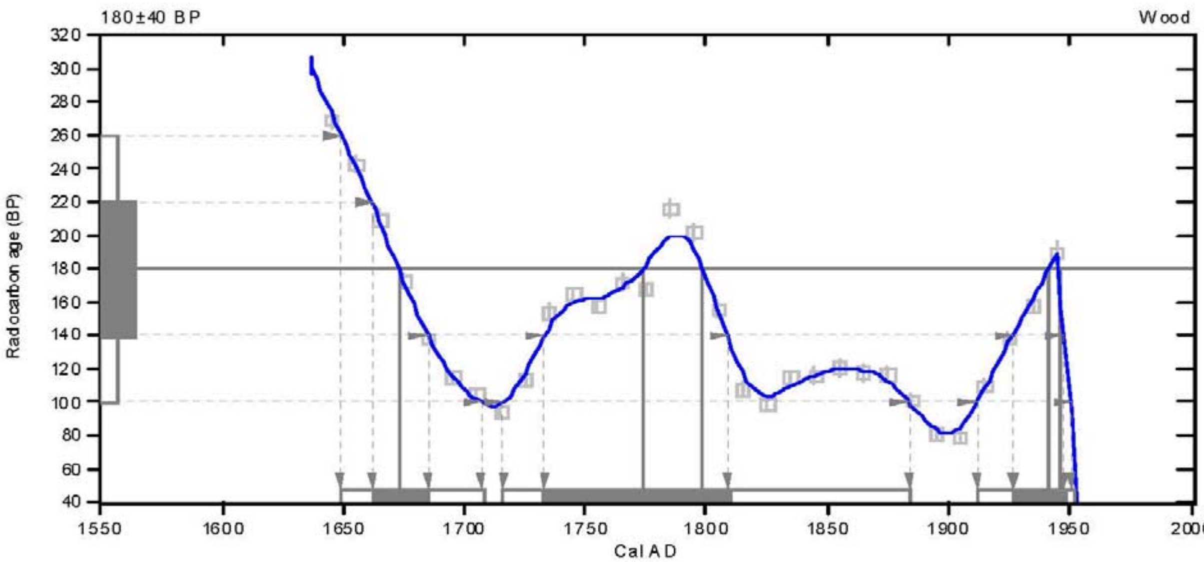


Fig 12 Results of the Carbon-14 dating.

Watershed delineation

The drainage divide on the GVSU property runs approximately north-south through the main part of campus as determined by the creation of the basins in ArcGIS (Fig. 13). It must be noted that this data is based on current topography as modified by campus structures.

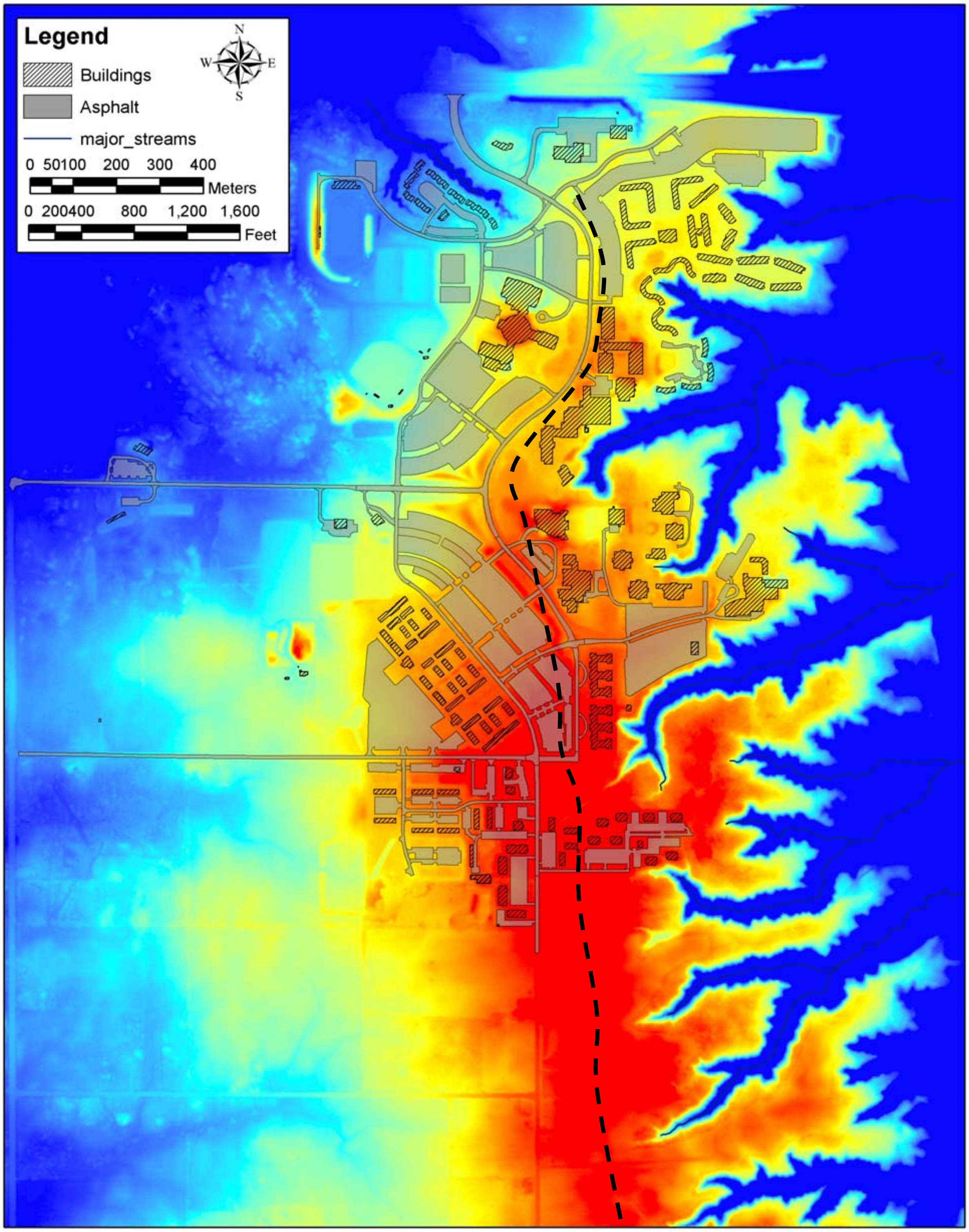


Fig 13 DEM of the campus showing the approximate location of the drainage divide (dashed line). Runoff flows away from the high areas in red towards the lower areas in blue to the east and west. Of note are the subtle drainages to the west of the divide (marked with arrows).

Stormwater allocation and watershed peak discharge

There are two watersheds that have changed the most after stormwater allocation: 22 and 11 (Fig 14 and Table 3). Watershed 22 drains the northern portion of campus and is discharged at the east end of parking lot D. Watershed 11 drains much of the southern campus including parking lots H and K which are on the western side of the drainage divide.

The three watersheds with the greatest increase in discharge, based on modeling a 1-inch per hour precipitation event, are number 22, 11, and16 (Figs 15 and 16). The peak discharge in watershed 22 may be overestimated due to the way the stormwater was allocated. The modeled discharge associated with watershed 22 was comparable to Sand Creek during a low flow period. Watersheds with the largest percent change were 22, 11, 16, and 4. Again, watershed 22 may be overestimated.

Table 3 The change in acreage between the original watersheds and effective watersheds between 1963 and 2004 based on the redirection of runoff through stormwater pipes.

Watershed ID	Acreage 1963	Acreage 2004	Difference	Percent Change
0	64.45	64.4	-0.09	0%
3	111.5	88.1	-23.4	-21%
4	29.2	17.7	-11.5	-39%
8	11.9	11.9	0.0	0%
11	131.6	144.0	12.4	9%
12	380.6	349.6	-31.0	-8%
14	78.7	96.9	18.2	23%
15	149.6	150.3	0.7	0%
16	89.9	91.1	1.1	1%
19	1.0	1.0	0.0	0%
20	12.3	12.3	0.0	0%
21	2.5	2.5	0.0	0%
22	26.7	61.8	35.1	132%
23	7.9	7.9	0.0	0%
24	24.5	24.1	-0.4	-2%
25	36.0	36.0	0.0	0%

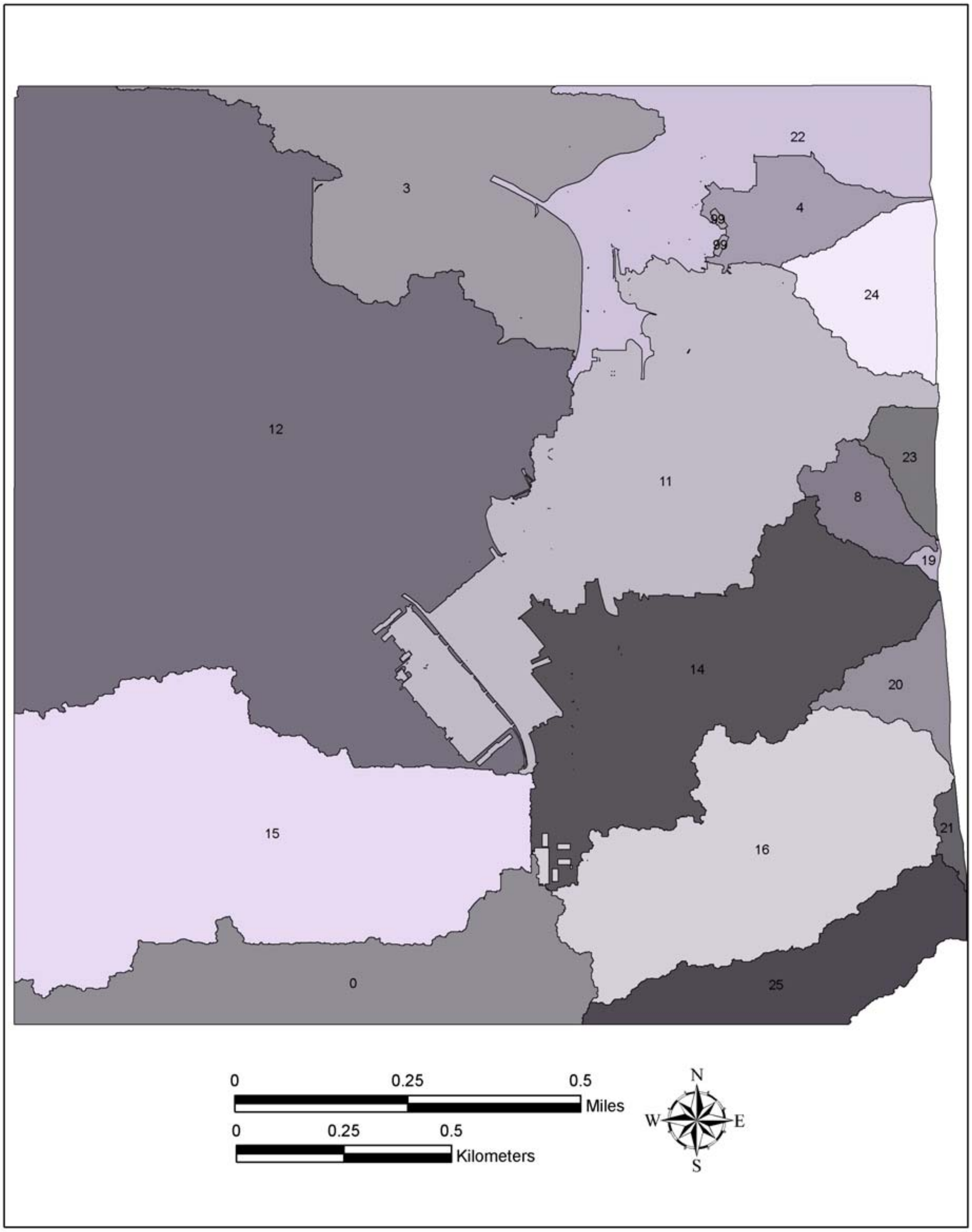


Fig 14 Effective watersheds based on stormwater allocation from stormwater pipes from impermeable surfaces.

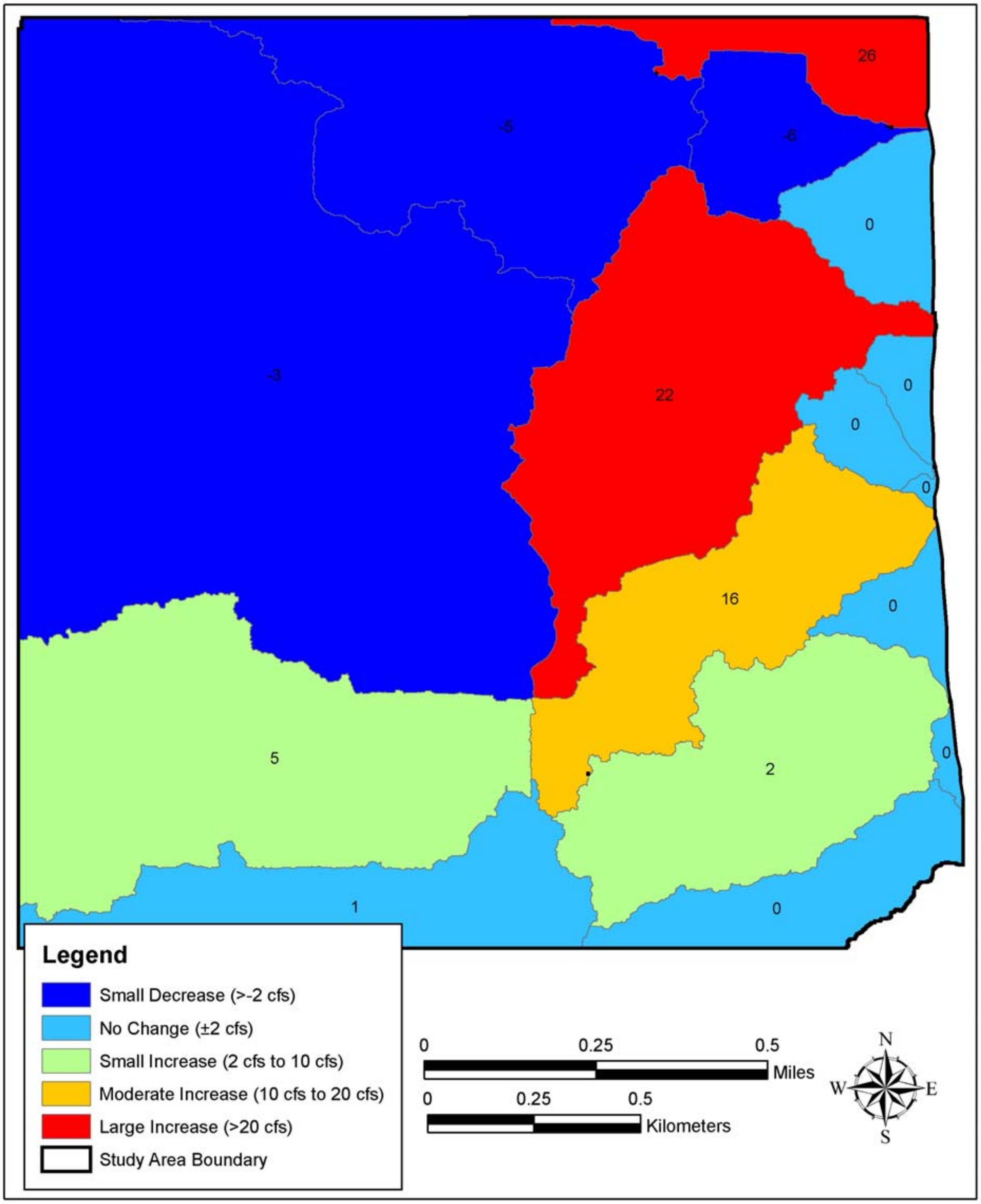


Fig 15 Modeled increase of peak discharge in watersheds in 2004 after stormwater allocation of a 1 inch/hour rain event.

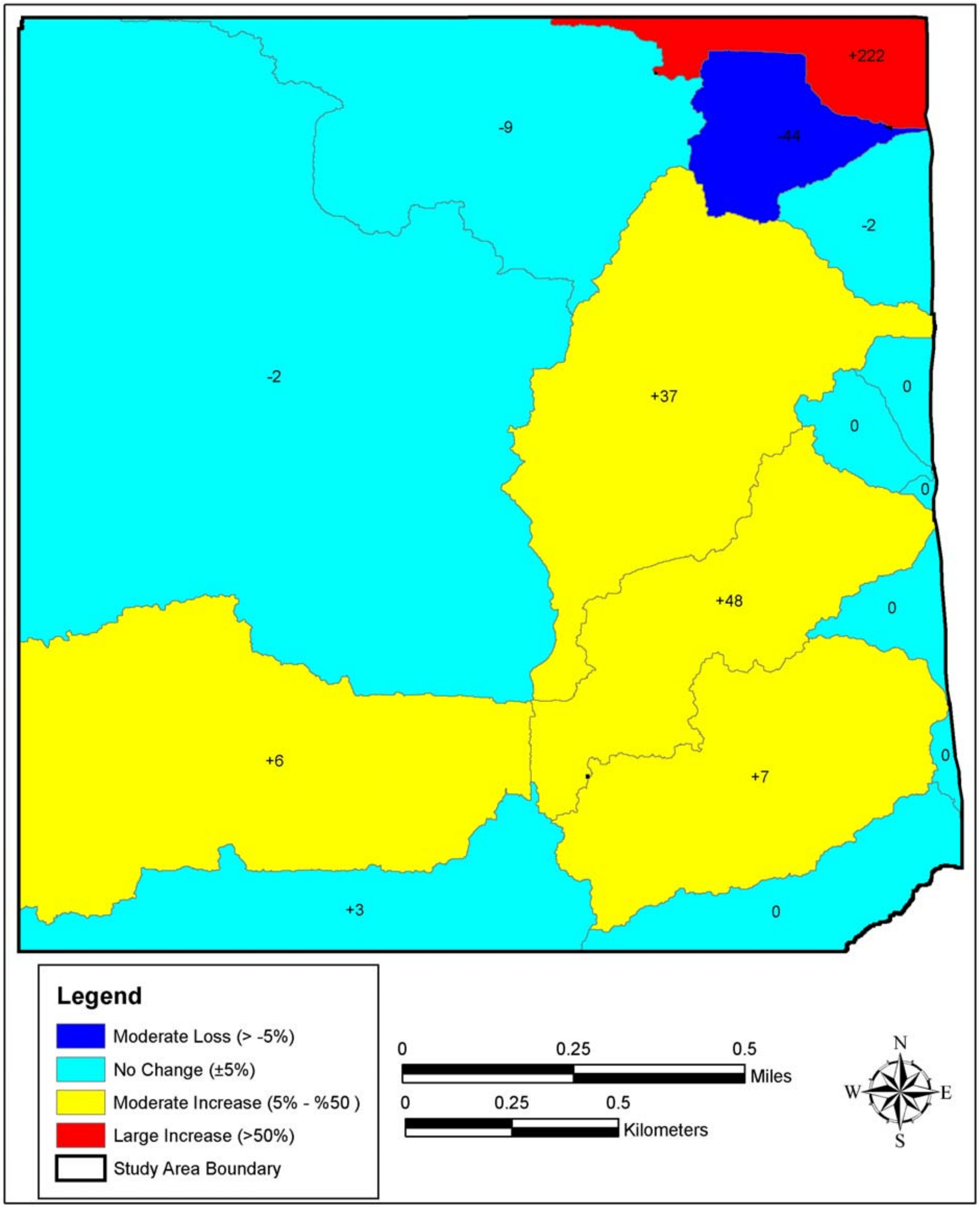


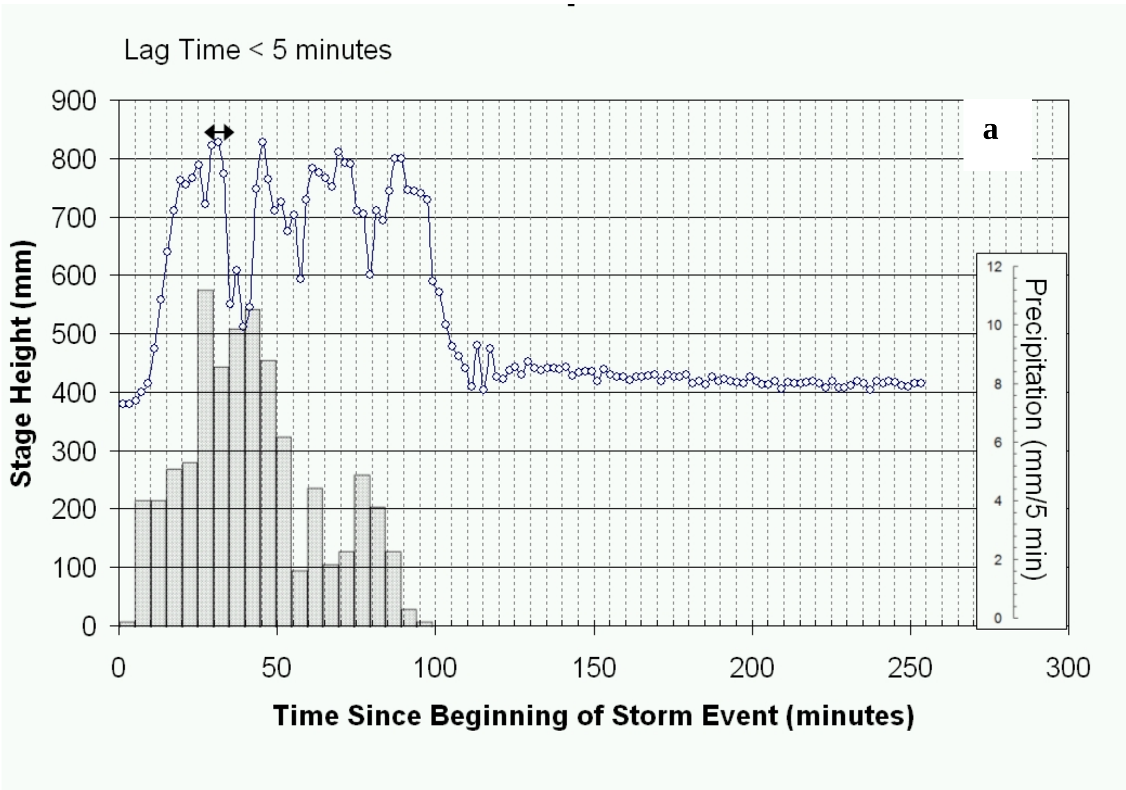
Fig 16 Modeled percentage increase of peak flow for watersheds in 2004 after stormwater allocation of a 1 inch/hour rain event.

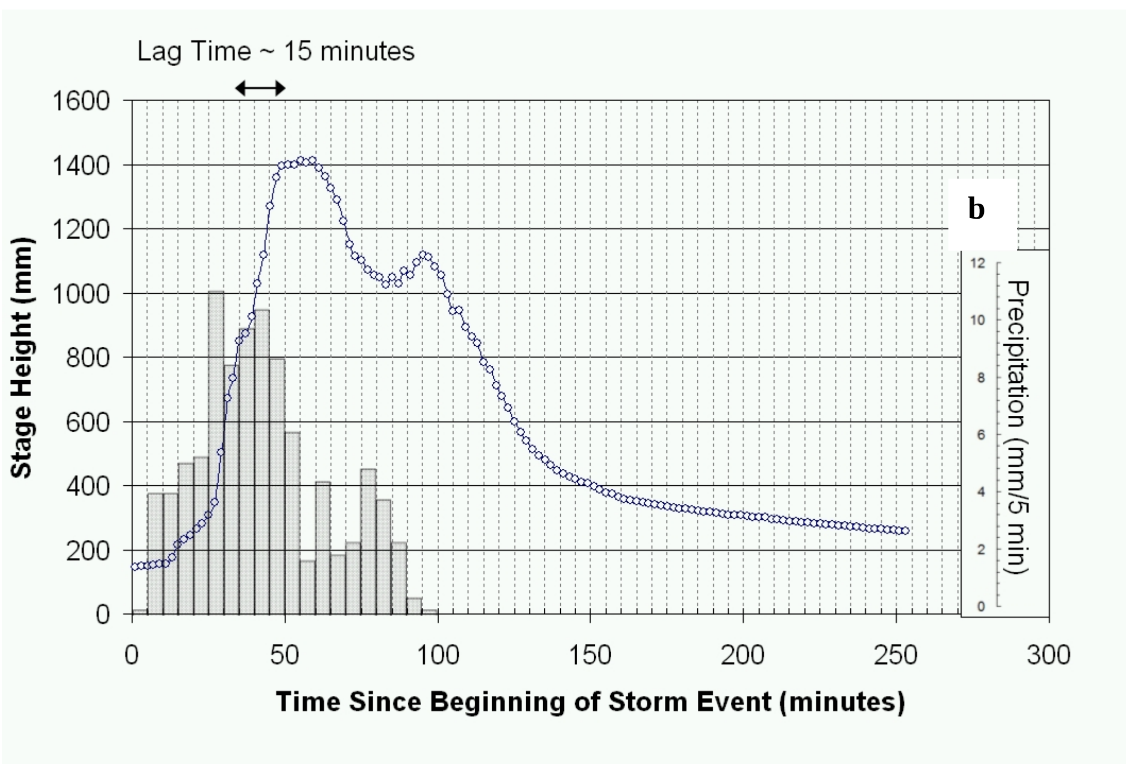
Table 4 Peak discharge change between original watersheds and destination watersheds between 1963 and 2004 based on peak runoff modeling at 1 in/hr intensity.

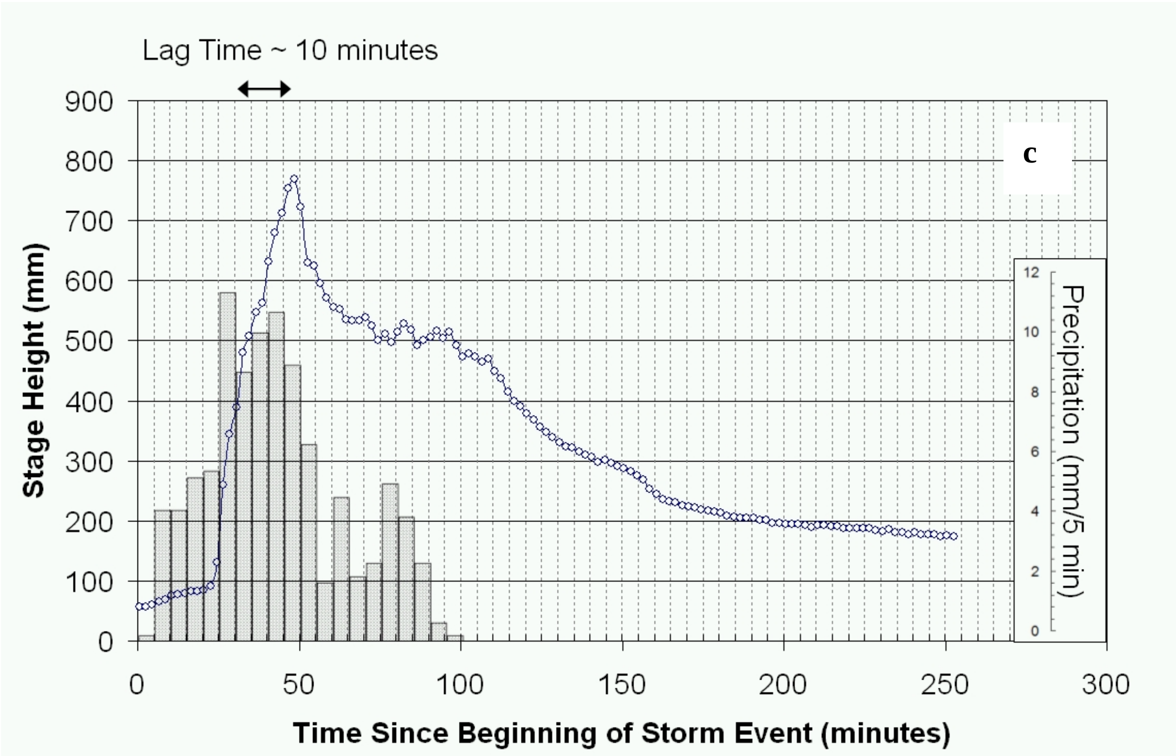
Watershed ID	1963 Qpk (cfs) @ 1 in/hr	2004 Qpk (cfs) @ 1in/hr	Difference	Percent Change
0	32.12	33.10	0.98	3%
3	55.75	50.74	-5.02	-9%
4	12.96	7.29	-5.67	-44%
8	4.78	4.78	0.00	0%
11	59.26	80.92	21.66	37%
12	190.32	187.06	-3.26	-2%
14	33.74	49.82	16.08	48%
15	74.81	79.37	4.56	6%
16	37.21	39.67	2.45	7%
19	0.40	0.40	0.00	0%
20	4.93	4.92	0.00	0%
21	1.01	1.01	0.00	0%
22	11.71	37.64	25.93	221%
23	3.17	3.17	0.00	0%
24	9.83	9.64	-0.19	-2%
25	14.67	14.67	0.00	0%

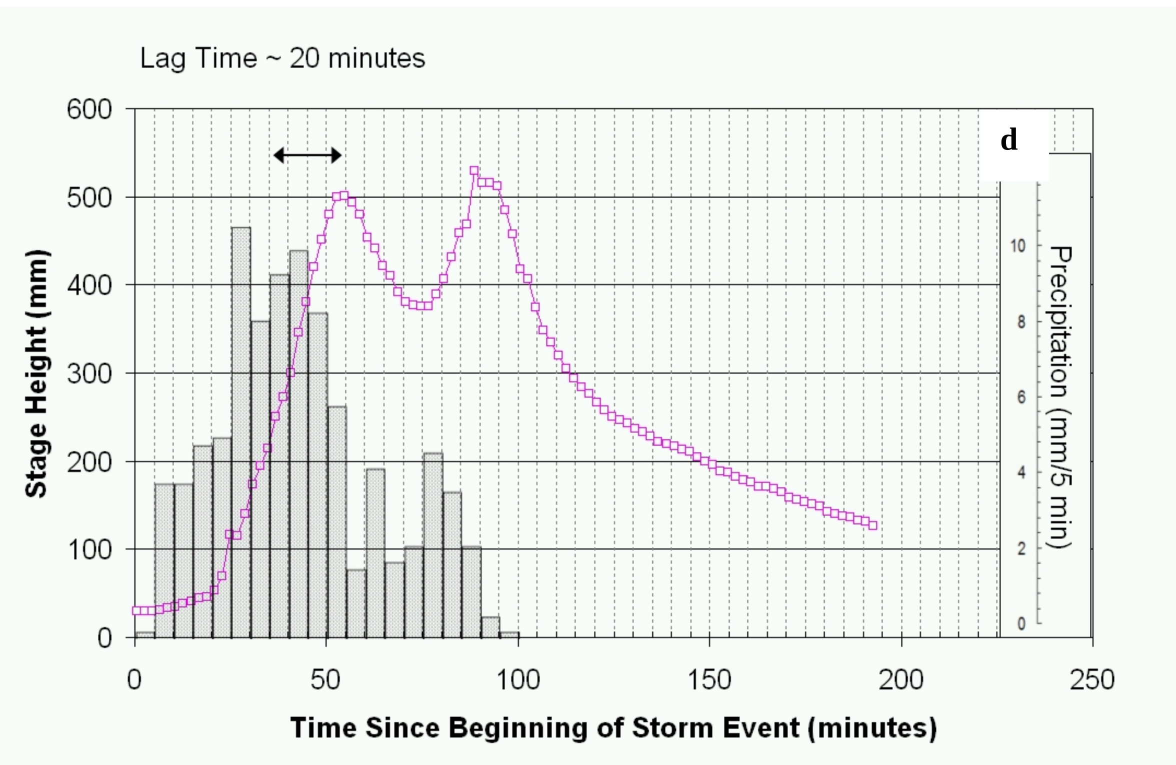
Lag Times

The lag times at the different stream gage sites varied quite a bit (Fig 17a-e). The shortest lag time (~5 minutes) was reported at Mordor, located in the concrete energy dissipation structure in the Little Mac ravine. The longest lag time (~175 minutes) was at the Gondor stream gage site in Sand Creek. The least impacted ravine (Shire) had a lag time of approximately 20 minutes while the most heavily impacted ravines (Little Mac at Fangorn and Isengard in the Calder ravine) had lag time of approximately 15 and 10 minutes respectively.


Lag Time < 5 minutes
a
Stage Height (mm)
Precipitation (mm/5 min)
Time Since Beginning of Storm Event (minutes)
0
100
200
300
400
500
600
700
800
900
0
50
100
150
200
250
300
0
2
4
6
8
10
12


Lag Time ~ 15 minutes
b
Stage Height (mm)
Precipitation (mm/5 min)
Time Since Beginning of Storm Event (minutes)
0
200
400
600
800
1000
1200
1400
1600
0
50
100
150
200
250
300
0
2
4
6
8
10
12


Lag Time ~ 10 minutes
c
Stage Height (mm)
Precipitation (mm/5 min)
Time Since Beginning of Storm Event (minutes)


Lag Time ~ 20 minutes
d
Stage Height (mm)
Precipitation (mm/5 min)
Time Since Beginning of Storm Event (minutes)

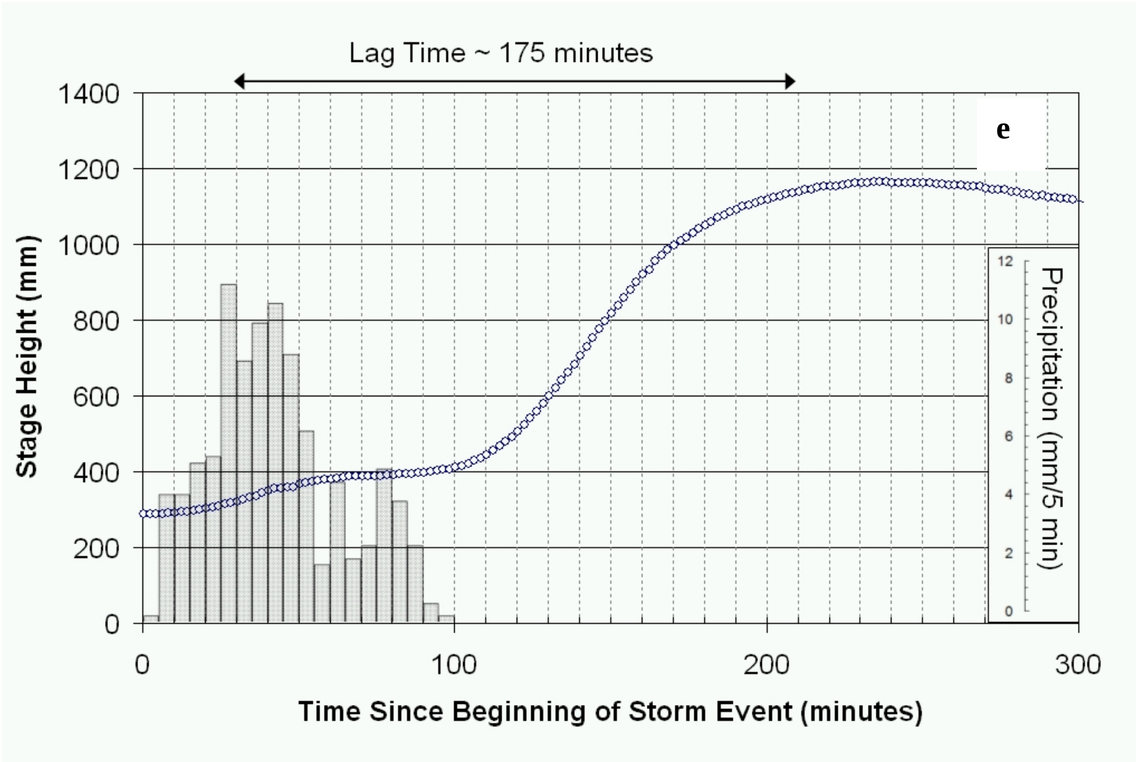


Fig 17 Combined hydrographs and hyetographs at stream gage locations a) Mordor b) Fangorn c) Isengard d) Shire e) Gondor during the July 17th, 2006 heavy rain event.

Pipe discharge

The measured discharge at Fangorn (watershed 11) on May 11th was 3.8 cfs (Table 5). The Sauron pipe contributed approximately 50% of the total measured discharge (Fig 18). The remaining discharge pipes measured constituted 25% of the total flow, while the remaining flow can be attributed to unmeasured tributaries and/or accretion. The modeled discharge, using the rational method, was approximately 8.0 cfs based on the average rainfall rate during the whole event.

Table 5 Discharge measurements collected during the rainfall event on May 11th, 2006 and the contribution of each discharge pipe to the whole system.

Discharge Pipe or Location	Q (cfs)	Percent of Fangorn
Fangorn (lowermost discharge measurement)	3.8	100
Gollum (left)	0.2	5.8
Gollum (right)	0.6	16.1
Sauron	1.9	50.6
Pippin	0.0003	0.008
Merry	0.002	0.04
Sam	0.004	0.1
Frodo	0.09	2.4
Total Discharge Measured above Fangorn	2.8	75.1
Unmeasured tributaries and/or accretion	0.9	24.9

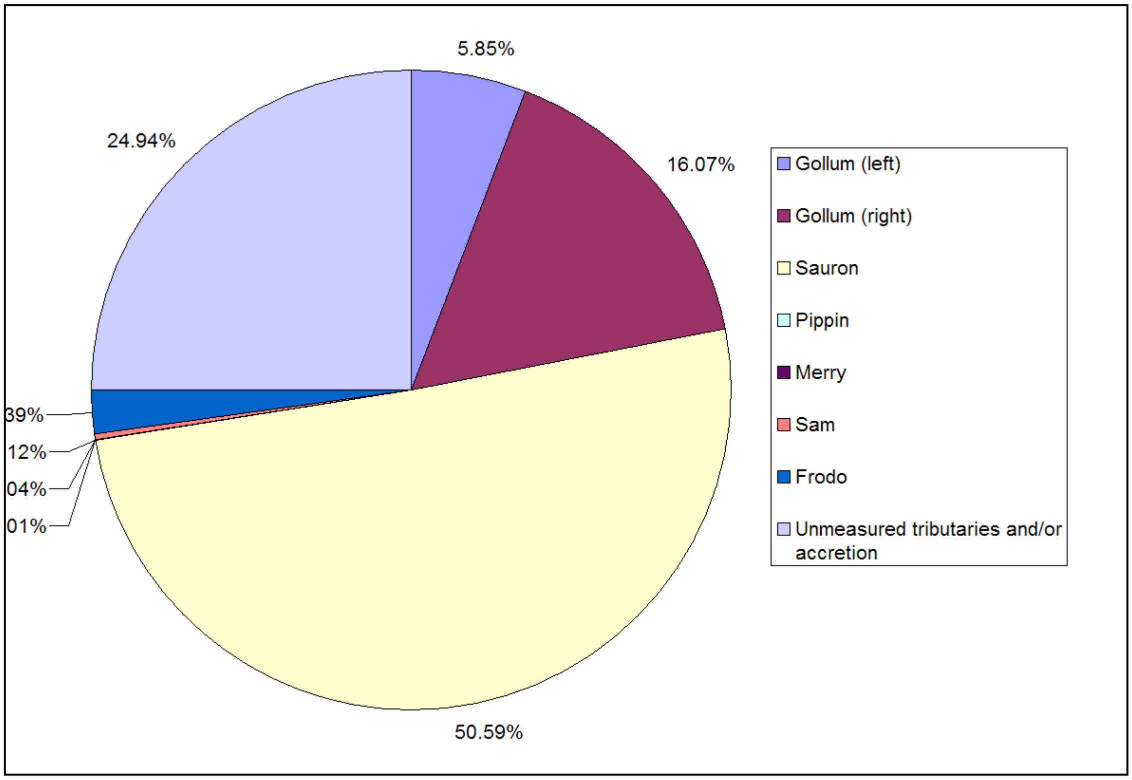


Fig 18 Pie chart showing the contribution that each stormwater pipe directing water into the Little Mac ravine has to the total discharge at Fangorn (Fig. XX).

Modern installed structures

Boulder armoring sites in the Little Mac and the Calder ravines are no longer structurally sound. The boulders are an argillaceous limestone which has allowed them to cleave along bedding planes, reducing their effectiveness. 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 (Fig 19a-b). Stormwater has also eroded into more easily erodable materials in the banks adjacent to armored areas. The undermining is worst and most damaging on steep slopes such as the slope near the Calder Art Center Saruman discharge pipe (Fig. 20).

The check dams installed in the ravine system are also not structurally sound. Baskets are beginning to rust and rocks from inside the baskets are being mobilized and removed into the stream. The baskets are beginning to collapse and in some places create more erosion. There is a large amount of sediment built up behind the second and third check dams in the Little Mac ravine as well as the check dam above the Saruman discharge pipe. The lowest check dam in the Little Mac ravine has just recently been circumvented by water during high flow, causing an erosional channel and pool to form downstream of it (Fig. 21).

Fig 19 a) Boulder armoring newly installed in the Little Mac ravine. Photo taken by P. Videtich, 09/03/2002. **b**) Boulder armoring failure in Little Mac ravine. Photo taken by P. Womble, 07/20/2006.

Fig 20 Boulder armoring failure and underlying blanket mobilization in a ravine tributary just south of the Calder Art Center. Photo taken by T. LaCross, 08/01/2006.

Fig 21 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, 07/20/2006.

DISCUSSION

Watershed delineation and stormwater allocation

There were several problems with the automated delineation of the watersheds. Due to the high resolution of the LIDAR data, the presence of manmade structures in the area caused premature terminations of watersheds 4, 14, 15, and 22. The watersheds defined in this project most likely would have looked different in their non-urbanized state. Hundreds of small (<2 acres) basins were defined and needed to be integrated into nearby watersheds or deleted all together. They were not kept in the study because they were mostly confined to buildings or roads and were not true watersheds or sub basins.

The runoff currently allocated into watershed 3 seems low for the amount of water and erosion observed in the Ravine Apartments ravine during rain events (Fig 22). This is most likely due to the delineation of the watershed and the allocation of stormwater. During the delineation process the watershed generated with the pour points around the Ravine Apartments ravine was merged with the much larger watershed 3. Instead of the increase of water appearing to be dramatic in the small watershed, the water is dispersed over a large area. Also, a possible incorrect allocation of stormwater would decrease the modeled amount of water directed toward the ravine. Therefore, even though there are three large parking lots that drain into that ravine, there is a 9% decrease in peak discharge during a 1 inch per hour rain event.

Fig 22 Discharge in the Ravine apartments ravine during the 9/23/2006 rain event.. Photo taken by P. Wampler on 9/23/2006.

The peak discharge modeled for watershed 22 could possibly be too high. The amount of water allocated to the discharge pipe during the mapping could have been overestimated. However, after inspection of the slope at the end of parking lot D, the numbers could very well be feasible. There is a large 36" discharge pipe at the end of the parking lot into a small detention pond with an outlet drain of similar size that directs water to a vertical energy dissipation structure at the bottom of the slope (Figs 23 and 24). This configuration would be able to handle the amount of runoff modeled in this study, possibly confirming the data. However, more information is needed to confirm or dismiss the accuracy of the stormwater allocation in the northern part of the campus.

Current measures to control runoff erosion 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. However, removal of them is not recommended until other solutions to detain runoff and reduce flow volumes can be explored. Ecologically sensitive alternatives, such as the reintroduction of beavers, should be explored. There are extensive areas on the west side of campus where engineered wetland detention structures could both provide storm water detention and valuable habitat.

Rip-rap placed in the ravines was installed with a boulder size range that was not large enough to withstand the forces acting upon the boulders during a large rain event. If these are to be effective, a combination of grain sizes of angular gravel, pebbles, and boulders should be placed several layers thick and properly keyed into the streambeds. This appears to be only a short-term solution and due to the complexity of the installation is likely not cost effective.

Stormwater detention and runoff volume reduction should be integrated into the design of any future changes to the infrastructure on campus. More runoff should be directed toward the west part of campus, perhaps into vegetated wetlands, even if this involves some redesign of stormwater pipe grades. Parking lot J is not currently utilized to its capacity and therefore could potentially be reduced in size to provide area for the installation of a stormwater detention structure. The area surrounding Laker Village and parking lots H and K could then be diverted to this structure, decreasing the amount on runoff into the Little Mac ravine. Smaller areas such as the grassed area behind the south Utilities building and ditches next to roads could also be used to drain smaller areas nearby.

Fig 23 Discharge pipe into small detention pond at the eastern end of parking lot D in watershed 22 (Photo taken by P. Womble, 09/23/2006).

Fig 24 Outlet drain of small detention structure at the eastern end of parking lot D (Photo taken by P. Wampler, 9/23/2006

Vegetated swales should be used in greater abundance to collect, detain, and disperse runoff. Current detention structures are doing what they were intended to do and provide evidence that these structures are effective in this setting (Fig 25). The stormwater infrastructure on campus should be modified to direct runoff into these structures.

Fig 25 Stormwater detention structure located at the intersection of South Campus Dr. and Calder Dr. partially full of water. Photo taken by P. Womble, 09/23/2006.

The installation of pervious concrete in areas with low traffic volumes, such as sidewalks, should be considered. Pervious concrete will prevent flooding on sidewalks and standing water, which is hazardous during the winter months.

Permeable asphalt should be used in all future parking lots. Water infiltrates quickly, preventing standing water and improving parking conditions during the winter months To provide more durability, permeable asphalt can be confined to just the parking spaces while traditional, nonporous asphalt could be placed surrounding the areas of high traffic. Permeable asphalt has also been shown to improve water quality by reducing and filtering out heavy metals and pollutants (Brattebo and Booth, 2003).

The general practice of concentrating runoff into a few locations then treating it with energy dissipation structures is resulting in numerous failures of engineered structures. A pilot experiment should be conducted to explore the effectiveness of distributed flows rather than concentrating them to determine if it is an appropriate stormwater management strategy for GVSU. GVSU should strive for a long-term goal of no net increase in runoff for all new development on campus.

Additional data is needed regarding the flow volume from all stormwater discharge points and the effectiveness of current stormwater detention methods on campus. Also additional measurements of discharge during runoff events are needed.

ACKNOWLEDGEMENTS

We'd like thank all those involved, including the College of Interdisciplinary Studies staff, Ted LaCross, Matthew Camp, Larry Henderson, Edwin Joseph, Leon Palmer, John Weber, Kevin Cole, Patrick Colgan, Robert Gould, Jeff Wollett, Ronnie Friend, and Patricia Videtich.

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