URBAN KARST DRAINAGE PROBLEMS IN THE ENSOR SINK – TIRES-TO-SPARE SYSTEM, COOKEVILLE, TN, USA

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Abstract

Ceiling failure in a cantilever dome produced a 30 m long, 13 m wide, 10 m deep collapse sink entrance to a cave in the Warsaw Fm. (Mississippian) beneath the city of Cookeville, TN. Exploration and mapping of the 630 m long virgin cave revealed urban debris in prodigious quantity and variety, including 30+ automobile tires, hence the name Tires-to-Spare Cave (TTS). Prior to the collapse, the cave stream transported tires and other large debris items through the entrance room; after the collapse, access to the upstream 380 m of passage was nearly blocked. A breakdown pile now acts as a strainer removing debris from cave floodwaters. A shopping cart and truck cargo seals of known provenance indicated the input point for the debris to be Ensor Sink (ES), 1.2 km straight line distance from TTS, but access to most of this underground conduit is blocked by permanent sumps at the ES swallet and in the upstream section of TTS.

ES, sinkpoint for Breedings Mill Branch (BMB), is the larger of two sinks which form a composite sinkhole. The surface drainage basin of ES, delineated with detailed contour maps (CI=2 ft), is approximately 325 hectares and that of the combined sinks approximately 405 hectares. Dye traces were performed to elucidate subsurface flowpaths in these basins. Using rainfall data, discharge data in BMB, and stage recorders in ES and other locations, we were able to define a number of characteristics of the BMB/ES - TTS drainage system.

About 34% of the BMB/ES watershed is impervious surface and much of the natural channel of BMB has been converted into a concrete canal, resulting in rapid runoff into ES. Extrapolation of our data yields a peak discharge of about 100 m^3/s during the 100 year storm event, whereas drainage rates from ES are calculated to be an order of magnitude less when flooded to a depth of about 10 m. This disparity between input and drainage rates results in frequent flooding of ES, which may hold up to 123,350 m^3 of water during the 100-year event. During our study period, flooding in ES damaged homes, submerged streets, and inundated recreational facilities in the Ensor Sink Natural Area.

Rapid flooding at ES suggests a chokepoint in the underground conduit near the swallet. However, stage-discharge relationships for ES, for the swallet in the adjacent portion of the composite sink, and for flooding in the entrance chamber to TTS imply more complex controls on flow through the cave between ES and TTS. The breakdown plug at the collapse entrance to TTS is a known constriction in the conduit. Rapid, total flooding of a portion of the cave occurs upstream from this breakdown pile. Peak stage in ES occurs 30 minutes to two hours before peak stage in TTS, showing that at the time of this study the breakdown plug in TTS was not the cause of flooding in ES. This is expected to change as the interstices of the breakdown "filter" become increasingly plugged by debris, a process observed during our study. If the influx of urban debris at ES remains uncontrolled, Cookeville will lose the services of an important natural storm sewer.

Introduction

On 25 April 1994, ceiling failure in a cantilever dome produced a collapse sink 31 m long, 13 m wide and approximately 10 m deep**.** The collapse broke through at least 2.5 m of bedrock to give entrance to a hitherto unknown active stream cave developed in the Warsaw Fm. (Mississippian) beneath the city of Cookeville, TN. Albeit a virgin cave, exploration and mapping of the 629 m long cave revealed it to contain urban debris in prodigious quantity and variety: Cans, cigarette butts, a plastic milk crate, automobile parts, toys, a baseball bat, one full beer, a pot, shoes, a lawnmower (?) wheel, commercial truck cargo seals, a shopping cart basket, 5-gallon buckets, lumber, motorcycle tires and over 30 automobile tires (one still on its rim!). The plethora of tires (Fig. 1) inspired the name Tires-to-Spare Cave (TTS).

Prior to the entrance collapse, the cave stream transported some large debris items (tires, buckets) through the cantilever dome room and on downstream. After the collapse, access to the upstream 381 m of passage was very nearly blocked. The breakdown pile now acts as a strainer removing all large and much small debris from cave floodwaters.

Figure 1: Four of over 30 tires in Tires-to-Spare Cave, accumulating at the base of the breakdown collapse.

A shopping cart and plastic truck cargo seals of known provenance indicated the input point for the debris to be Ensor Sink (ES), 1220 m straight line distance from TTS, but access to most of the underground conduit between the two is blocked by permanent sumps in the upstream section of TTS and 10 m inside the ES swallet. The hydrologic connection between ES and TTS was reconfirmed by a rhodamine-WT dye trace on April 8, 1995, with positive results.

ES is the sinkpoint for Breedings Mill Branch (BMB), which drains approx. 325 hectares (800 acres) of Cookeville. The BMB drainage basin includes both residential and commercial areas. At the time of this study, about one third of the basin was covered by impervious surface. In 1984, the city of Cookeville spent over $600,000 to improve stormwater drainage in the BMB basin, hiring an engineering firm to a) clean out the debris-choked ES swallet, b) line 225 m of the stream channel in the sinkhole with riprap, and c) convert 850 m of BMB into a concrete-lined canal.

Today, due to the combination of widespread impervious cover and the canalization of BMB, stormwater runoff into ES is very “flashy” and the sinkhole is subject to rapid flooding several times a year. Flooding is generally harmlessly confined to the sinkhole area proper, but upon occasion has overtopped two city streets and damaged one or two houses. In addition to damage and inconvenience, floods in ES and BMB pose a safety hazard to children in the area, who find the BMB canal an attractive play area.

A second sinkhole, Walmart Sink (WMS), draining approximately 60 hectares (150 acres), lies adjacent to ES. The sinkholes are currently separated by a divide, but when ES floods to a depth of approx.10 m, there is overflow via a surface paleochannel from ES into WMS.

The primary purpose of this study was to better characterize the flooding and drainage of ES and provide the city of Cookeville with recommendations for preserving this natural storm drainage so essential to the city’s welfare.

<u>Drainage basin characterization</u>

Most of the city of Cookeville is drained through sinkholes. Previous work in the area had established connections between a number of sink points and 6.6 km long Capshaw Cave, which resurges at a spring at the head of a short karst window stream known as “The Canal”. The Canal stream, which was thought to also be the resurgence point for ES, disappears underground to pass through Ament Cave before resurging for a final time as the principal source for Pigeon Roost Creek, a tributary to the Caney Fork River.

Tracing performed in 1995 established that drainage from ES passes through TTS. The Canal stream sinks to join the downstream end of the TTS cave stream and the combined waters flow through Ament Cave. A second dye trace showed that drainage from WMS also joins the TTS cave stream. A final dye trace from a third sink lying between WMS and TTS indicated that water sinking here connects into both the TTS cave stream and into the spring at the head of The Canal.

The BMB and WMS drainage basins were delineated using a topographic map with a 2-ft contour interval. Drainage boundaries in these basins may not correspond exactly with topographic divides due to extensive storm water drains and karstic flowpaths in the subsurface, but tracing results in adjacent basins indicate that such errors are minimal.

Rainfall within the BMB basin was estimated using a Rain Wise recording rain gauge deployed near the center of the basin, augmented at times by additional rain gauge measurements at other points in the drainage area. The recording rain gauge provided a record of rainfall amount and intensity at intervals of five minutes, at least for the center of the 325 hectare BMB watershed.

Flood stages in the BMB canal, ES, WMS, and the TTS entrance chamber were recorded through time with In-Situ model 4000 and 8000 data loggers (Trolls). To guard against vandalism the Trolls were hidden or camouflaged. Additional measurements were made by tape and clino surveys to high water levels observed and marked. Discharge from BMB canal into ES was calculated to determine a stage – discharge relationship for ES.

Stage measurements in the sinkholes and discharge rates from BMB canal were used with sinkhole stage-volume relationships to compute average sinkhole drainage rates in ES over five-minute intervals for various water depths (Fig. 2). Knowing approximate drainage rates and watershed characteristics, flood levels for storms not witnessed during the course of the study (such as the 100-year storm) were predicted.

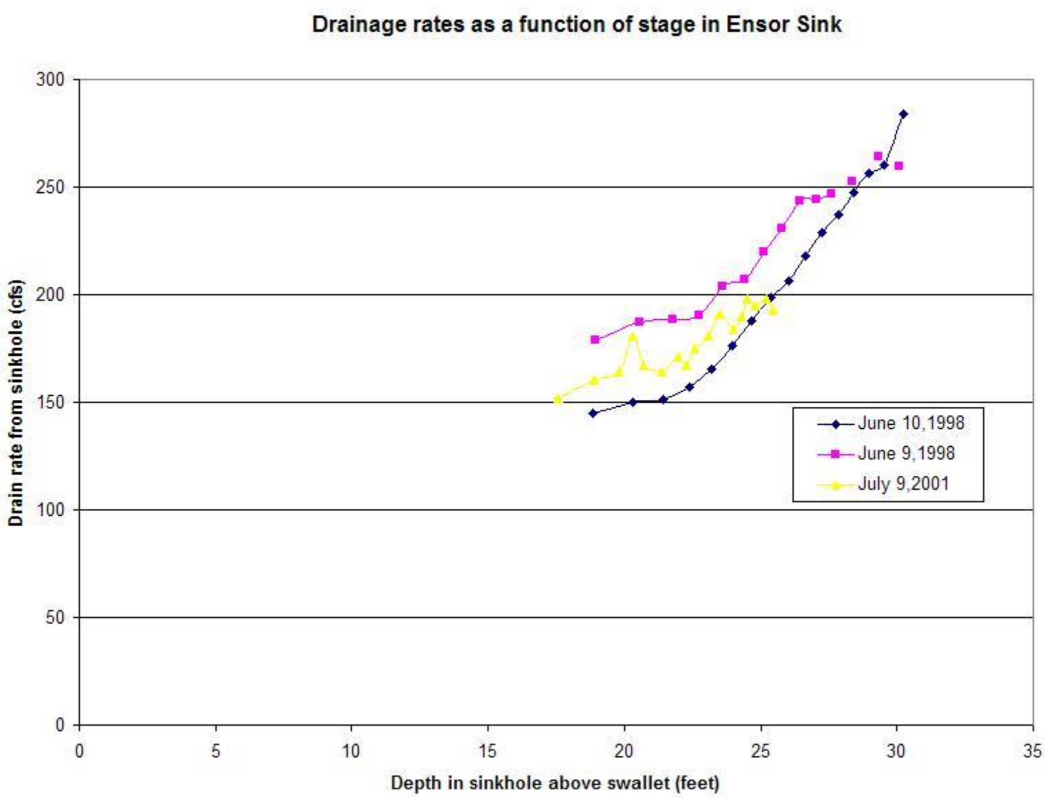

Figure 2: Drainage rates at Ensor Sink as a function of stage

Characterisitics of flooding at Ensor Sink & Walmart Sink

Due to urbanization of the watershed and modification of the BMB channel, storm water runoff in the BMB basin is routed quickly to ES. The lag time between maximum rainfall intensity and peak discharge into ES measured during this study was typically between 15 and 30 minutes.

The BMB canal design allows brimfull discharge of approximately 28 m^3/s (1000 cfs) near its terminus at ES. Hydrologic models incorporating our data indicate a peak discharge between 70 – 115 m^3/s (about 2500 – 4000 cfs) during the 100-yr storm event, during which ES may hold up to about 125,000 m^3 (100 acre/feet) of water in temporary storage. In contrast, drainage rates from ES, as a function of stage, were calculated to be an order of magnitude less than the input: approximately 4.2 – 4.5 m^3/s when flooded to a depth of 6.1 m (20 ft), and approximately 7.4 – 7.9 m^3/s (260-280 cfs) when flooded to a depth of 9.1 m (30 ft).

This disparity between input and drainage rates accounts for the frequent local flooding of ES. After this study was initiated, the city of Cookeville took several steps to mitigate the impacts of flooding in ES. One road was raised and a bridge was rebuilt. Two homes subject to flooding were purchased and removed, and much of the area around the ES swallet was designated a natural area and made into a small public park.

During the time period spanned by this study, 1998-2001,18 ES flood events with water depth >6.1 m (20 ft) were recorded (max recorded depth = 11.6 m). At least two events produced a merger of the ES and WMS flood ponds inundating recreational facilities in the Ensor Sink Natural Area, in addition to damaging homes and overtopping one bridge.

Causes of flooding at Ensor Sink

The rapidity with which ES floods suggests a chokepoint in the cave conduit not far downstream from the ES swallet. However, estimates of ES drainage rate do not display the functional dependence on stage (one-half power) anticipated for a single orifice type constriction. Simultaneous stage peaks in ES and adjacent WMS, recorded during a June 1998 flood event (which did not produce merger of the two sinkhole flood ponds), suggest that at least one flow restriction lies downstream from the WMS input, causing simultaneous backup in both sinks.

During another flood event, which caused pond merger, prominent surface flow was observed from ES to WMS, suggesting that the flow restriction at the ES swallet and/or additional constrictions between the two sinks create sufficient gradient to cause overland flow to WMS.

In contrast to the June 1998 flood event, during a Dec. 1998 event stage synchronicity was less perfect, with ES remaining flooded to higher levels for a longer time. There are at least two possible explanations for the disparity: 1) Rainfall intensity variations in the two drainage areas (we had no rain gauge in the WMS drainage basin); the WMS basin may have received lower intensity rainfall. 2) As previously suggested, flow constriction in the underground conduit between ES and WMS may result in some difference between sinkhole water levels for less intense storms. Some increase in this suggested partial blockage (possibly due to the continued influx of trash items into the ES swallet) might cause ES to flood higher and drain more slowly. More data are needed to resolve this question.

Another apparent restriction in the underground conduit occurs at the upstream sump in TTS where the cave passage size abruptly diminishes from walking passage to a low water-filled tube.

The fourth and best known constriction in the subterranean drainage is formed by the breakdown plug at the collapse entrance to TTS. Rapid, total flooding of a portion of the cave upstream from this breakdown pile is known to occur.

Does blockage in TTS cause flooding in ES? Not at the time of this study. Peak stage in ES occurs 30 min to two hours before peak stage in TTS, showing that, at the time of this study, the breakdown plug in TTS is not the principle cause of flooding in ES.

This, however, might be expected to change as the interstices of the breakdown "filter" become increasingly plugged by debris. (Fig. 3). During the course of this study an increase in ponding on the upstream side of the breakdown was observed, hinting at growing blockage in the lower levels of the breakdown pile. Additionally, an apparent increase in the degree of in-filling by trash of the interstices higher up in the breakdown “filter” was noted. If steps are not taken to control the influx of urban debris at ES, Cookeville may lose the services of an important natural storm sewer.

Figure 3: Tire on rim, cans, sticks, sediment, and other debris filling the interstices of breakdown “filter” in TTS Cave.

Conclusions and recommendations

Based on the results of our study, the following recommendations were made to the Cookeville City Council (which funded this study):

1) That ES be thoroughly cleaned out: removal of some of the rip-rap that has washed into the swallet, and removal of all the trash currently in ES.

2) Installation of a “trash rack” or strainer structure near the end of the BMB canal, at a point accessible for service. The structure would strain out trash from floodwaters entering ES and thereby reduce the influx of solid trash into the underground conduit, lessening the probability that this conduit will become totally blocked.

3) Regular inspection and maintenance of the trash rack: removal of the collected debris after floods, to keep the trash rack functioning properly, and to insure that it does not itself become a cause of ponding and flooding.

4) Installation of one or more, smaller, subsidiary trash racks elsewhere in the BMB drainage to strain out some of the debris before it reaches the main trash rack at ES.

5) Installation of fencing along the upstream sections of the BMB canal, to reduce the amount of urban debris being washed into BMB, while simultaneously enhancing the safety of children living near the canal.

Total plugging of the ES-TTS conduit at any of the several known and suspected conduit restrictions (or other undetected choke points) would necessitate construction of a 1.2 m (4 ft) diameter storm sewer at least 1220 m (4000 ft) long, blasted through bedrock, at great cost to the city of Cookeville. Fourteen years after this problem was reported, and five years after the results of this study were presented to the city none of the above recommendations have been implemented. The city of Cookeville is considering the construction of a sump basin to extract bedload trash out of storm water runoff entering ES, combined with a floating screen to remove floating trash. However, to date these plans remain tentative, with no final design determined. The only concrete steps taken to reduce the amount of urban debris entering the ES-TTS conduit have been several trash clean-ups of ES performed by a local environmental activist group.