STORMWATER MANAGEMENT IN A SMALL MICHIGAN WATERSHED

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Abstract: This study examines stormwater flooding problems on Arcadia Creek, a typical small watershed in Michigan, which is undergoing urbanization. Land-use change has increased the impervious area and, hence, surface runoff while decreasing the natural storage capacity along the channel by elimination of marshes and swamps. However, creation of flow constrictions at culverts, construction of retention ponds, and other results of human interference have led to hydrologic segmentation of the basin and less downstream discharge but a more peaked hydrograph than expected. Continued haphazard urbanization of the basin could increase runoff and decrease storage to a point where downstream flooding would become a far more serious problem. A cooperative approach is needed among the three governments who have jurisdiction over the basin to preserve upstream storage capacity through both structural and policy measures. This would not only greatly facilitate flood control but obviate the need for expensive channel reconstruction to increase conveyance capacity.

The impact of urbanization on the hydrologic response of small drainage basins is well documented. It increases peak runoff as pervious areas are converted to impervious, leading to less infiltration and more surface flow. Urban expansion also prompts the installation of storm sewers to increase conveyance and prevent local flooding. However, this also decreases the lag-time of a storm-runoff event and concentrates the volume of flow which exacerbates downstream flooding. Leopold (1968) indicates that heavily urbanized small drainage basins can experience a five- or sixfold increase in their mean annual flood over natural conditions. Thus, more frequent damaging floods are a concomitance of urbanization. Public pressures to alleviate the problem usually result in expensive public works projects to construct or renovate downstream conveyance facilities to handle more flow. As urbanization spreads, therefore, more of the basin is affected by flooding of increased intensity.

The construction or improvement of the conveyance network is not the only approach to stormwater management. Stephenson (1981) states that policy can play an important role in addition or as an alternative to purely structural measures. For example, the retention of stormwater, recharge of groundwater, and dispersion of impervious areas can be mandated and require little channel modification. Planning and zoning policy may also be used to control land use in such a way as to minimize peak flow increases or their harm.

This study examines a small watershed which has experienced urbanization and, owing to this, more frequent damaging stormwater floods. The impact of urbanization on basin runoff is estimated through an analysis of land-use change and application of the rational method for calculating runoff. The response of the basin to a

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typical major storm, based on field observations, is described. This response is explained in terms of the basin's hydrologic characteristics and appropriate adjustments are made to the basin discharge figures derived via the rational formula. Finally, the lessons of this analysis are presented as an aid to stormwater planning and management in other small drainage basins undergoing urbanization.

ARCADIA CREEK BASIN

Arcadia Creek watershed is a small drainage basin in Kalamazoo County, Michigan. Prior to urbanization, the creek originated in a marsh, flowed approximately 8 km across slightly undulating topography, and entered the Kalamazoo River. The drainage basin is oriented east-west and has a total surface drainage area of 19.61 km^2. The slopes within the basin range from negligible to 4% and the primary soil type is sandy loam. The creek drains the CBD and west portion of the city of Kalamazoo and parts of Kalamazoo and Oshtemo Townships. Prior to development, the creek meandered through low swampy areas for approximately 4 km.

Approximately 80 years ago, the growth of Kalamazoo dictated the first of many man-related changes in the drainage system. Arcadia Creek was encased in brick and stone arch sections over the last 2 km before it entered the Kalamazoo River to facilitate the expansion of the rapidly growing city. Since that time, additional sections of the creek have been encased in concrete pipe or box culverts or contained in lined ditch channels. Its course has been straightened and altered to facilitate the development of the road and highway network. The natural drainage underwent major changes as the basin was urbanized. Some low and swampy areas were converted to permanent retention ponds. Lateral sewers were constructed to convey stormwater to the creek more rapidly. Culverts were installed to carry the creek beneath roads and highways. Arcadia Creek typifies the fate of most small drainage systems: the change from a sinuous creek to a highly modified and linearized channel network as settlement and urbanization proceeded.

LAND-USE DATA

Only part of the basin was used for this study. A stream-gaging site was established at the point where the creek flows beneath a major arterial road and first becomes encased over a lengthy stretch. This eliminated the downtown area from evaluation. Development in this area is complete and little change could occur to alter further discharge characteristics. The study area was the 1,774 ha of the basin above the point of observation (Fig. 1).

The impact of land-use changes characteristic of urbanization within the basin was determined from aerial photographs which are available for the years 1938, 1950, 1964, and 1974 (Abrams Aerial Survey; Coder, 1978). Over this period, there has been substantial increase in the area devoted to uses that reduce permeability and increase runoff and a concomitant decrease in seminatural and agricultural lands with high porosity (Fig. 2).

Low runoff uses (for which a high percentage of rainfall infiltrates the soil) such as woods, parks, and unimproved areas, fell from 95% to 57% of the basin area between 1938 and 1974. High runoff uses (for which a substantial percentage of rainfall

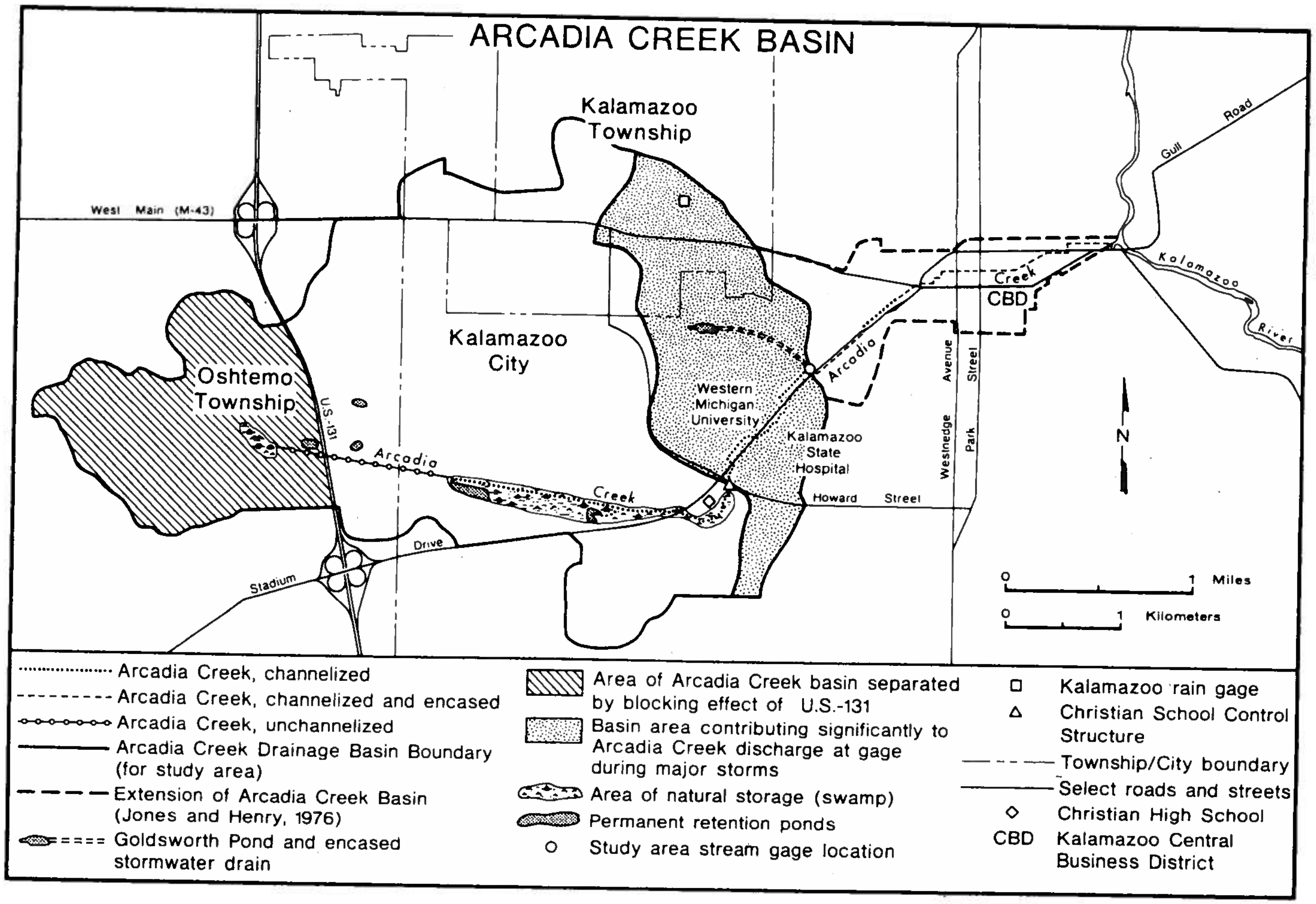


Fig. 1. Arcadia Creek drainage basin, Kalamazoo, Michigan.

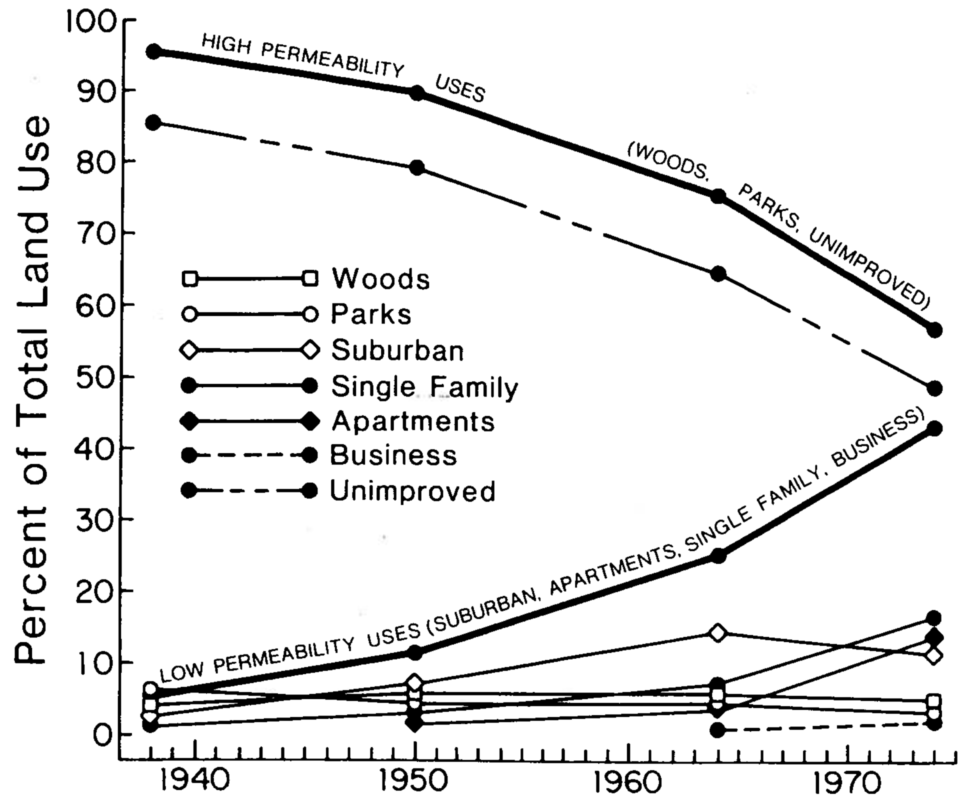


Fig. 2. Land-use changes in the Arcadia Creek basin for 1938, 1950, 1964, and 1974. Total basin area is 1,774 hectares (17.74 km^2).

becomes surface flow), such as suburban, single family, apartments, and business, rose from only 5% of the basin in 1938 to 43% in 1974, an increase of nearly eight-fold. Urban land uses grew especially rapidly between 1964 and 1974, increasing from 451 ha to 765 ha, a growth of 70% or 5.4% per year. Within this classification, apartments and single family uses grew substantially whereas suburban land use decreased (Fig. 2).

ESTIMATES OF RUNOFF

The rational formula was used to estimate the volume of runoff for selected storms for the 4 study years. The formula assumes that both surface retention and soil moisture requirements have been met and that storm duration is equal to or greater than the time of concentration for the basin (Chow, 1974). The equation is

$$Q = C I A$$

where Q is the flow rate in cubic meters per second (cms), C is the runoff coefficient,

Table 1. Runoff Coefficients Used to Calculate Peak Discharge from the Arcadia Creek Drainage Basin (Rational Method)

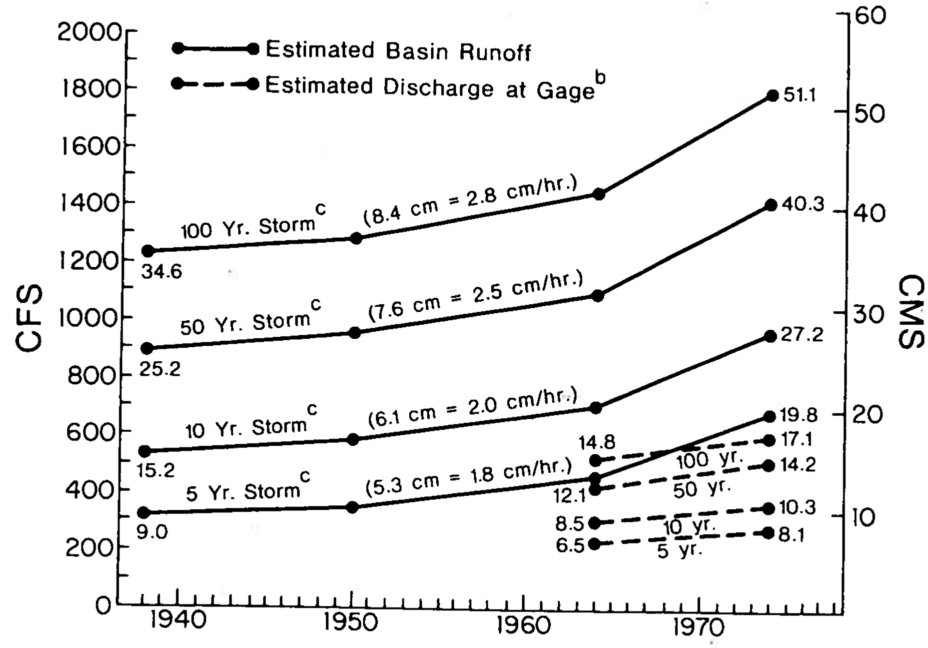
Land use	Runoff coefficients			
	Storm recurrence interval (years)			
	5(5.3 cm/3hr)	10(6.1 cm/3hr)	50(7.6 cm/3hr)	100(8.4 cm/3hr)
Woods	0.00	0.05	0.10	0.15
Parks	0.05	0.10	0.15	0.20
Suburban	0.25	0.30	0.35	0.40
Single family	0.35	0.40	0.45	0.50
Apartment	0.55	0.60	0.65	0.70
Business	0.70	0.75	0.80	0.85
Unimproved	0.10	0.15	0.20	0.25

I is the average rainfall intensity in cm per hour for a specific storm duration, and A is the area in hectares. The runoff coefficient (that portion of the precipitation that is classed as excess and ends up as surface and interflow) is normally assigned a value less than one. Its magnitude depends on the nature of the surface, surface slope, degree of saturation, and rainfall intensity (Gray, 1973). Values of C are generally given in terms of ranges related to these influencing parameters. However, C should theoretically increase with rainfall intensity (Stephenson, 1981).

The time of concentration for the study area is estimated at 2 hours. Therefore, in utilizing the rational formula, a storm event of 3 hours was assumed (in order to meet the formula assumptions). The rainfall intensities for selected 3-hour storms with recurrence intervals of 5, 10, 50, and 100 years were determined from the Kalamazoo rainfall probability chart (Jones and Henry Engineers, 1976). The runoff coefficients employed for each storm recurrence interval and rainfall intensity are listed in Table 1. The runoff coefficient was incremented by 0.05 as intensity increased to account for less infiltration and higher runoff associated with more intense precipitation (Urban Drainage Subcommittee, 1977).

Because of urbanization, estimated basin runoff increased significantly between 1938 and 1974 (Fig. 3). The 5-year rainfall event produced predicted values of 9.0 cms for 1938 but 19.8 cms for 1974 (a 10.8 cms or 121% growth). The 10-year rainfall runoff grew 12.0 cms (79%) from 15.2 to 27.2 cms. The 100-year storm produced a 16.5 cms (48%) increase from 34.6 to 51.1 cms.

In an effort to evaluate the accuracy of values of basin discharge estimated via the rational formula, an 8-day stage-height recording gage was established at the lower end of the study area where Arcadia Creek flows through a concrete culvert (cross-sectional area of 2.9 m^2; Fig. 4). Flow measurements were taken using a Teledyne-Gurley current meter. Low flows were easily acquired; however, high flow readings were not obtainable owing to excessive current velocity which along with other storm phenomena (e.g., lightning) made the measuring procedure difficult and dangerous. Consequently, for storm events of interest, field data are limited to water levels rather than discharge since it was impossible to establish a rating curve. Discharge estimates for major storms were made using indirect methods applicable to culverts but these are only approximate (Bodhaine, 1968).



[a] Calculated according to the Rational Method (Q = CIA), where Q = discharge in cms, C = runoff coefficient, I = rainfall intensity in cm per hour, and A = area in acres, time of concentration is estimated at 1 - 2 hours.

[b] The difference between basin runoff and discharge at the gage location is accounted for by storage in closed depressions, retention and ground water recharge basins, and low and swampy areas along the channel.

[c] Average return period or reciprocal of annual exceedance probability.

Fig. 3. Estimated peak runoff from Arcadia Creek drainage basin for selected three hour storms: 1938, 1950, 1964, and 1974.[a]

TYPICAL MAJOR STORM

To evaluate the accuracy of the predicted discharge values, and also to assess the response of the stream to a major storm event, an analysis of a suitable storm was conducted. The storm selected occurred June 7, 1979. Hourly precipitation records were acquired for the city of Kalamazoo from the U.S. Weather Bureau (NOAA, 1979). The published data are collected at a site 2 km (1.25 miles) NE of the gaging location and are believed to be a reasonably accurate record of precipitation for the study area. The published data were then chronologically matched to the stage-height recording acquired for the same storm event (Fig. 5). The intensity for the heaviest

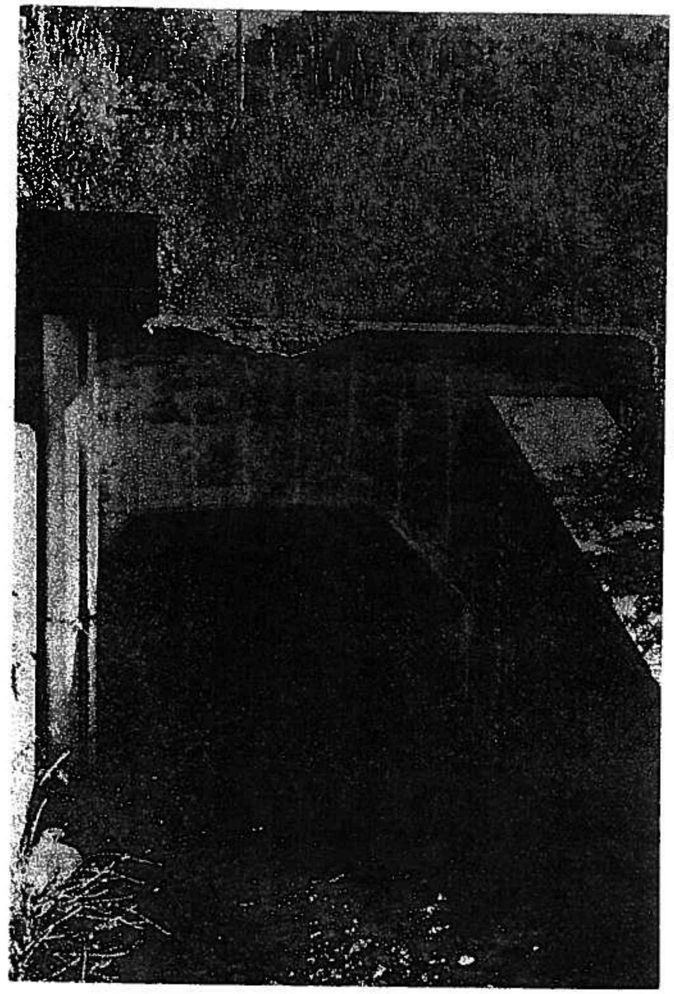
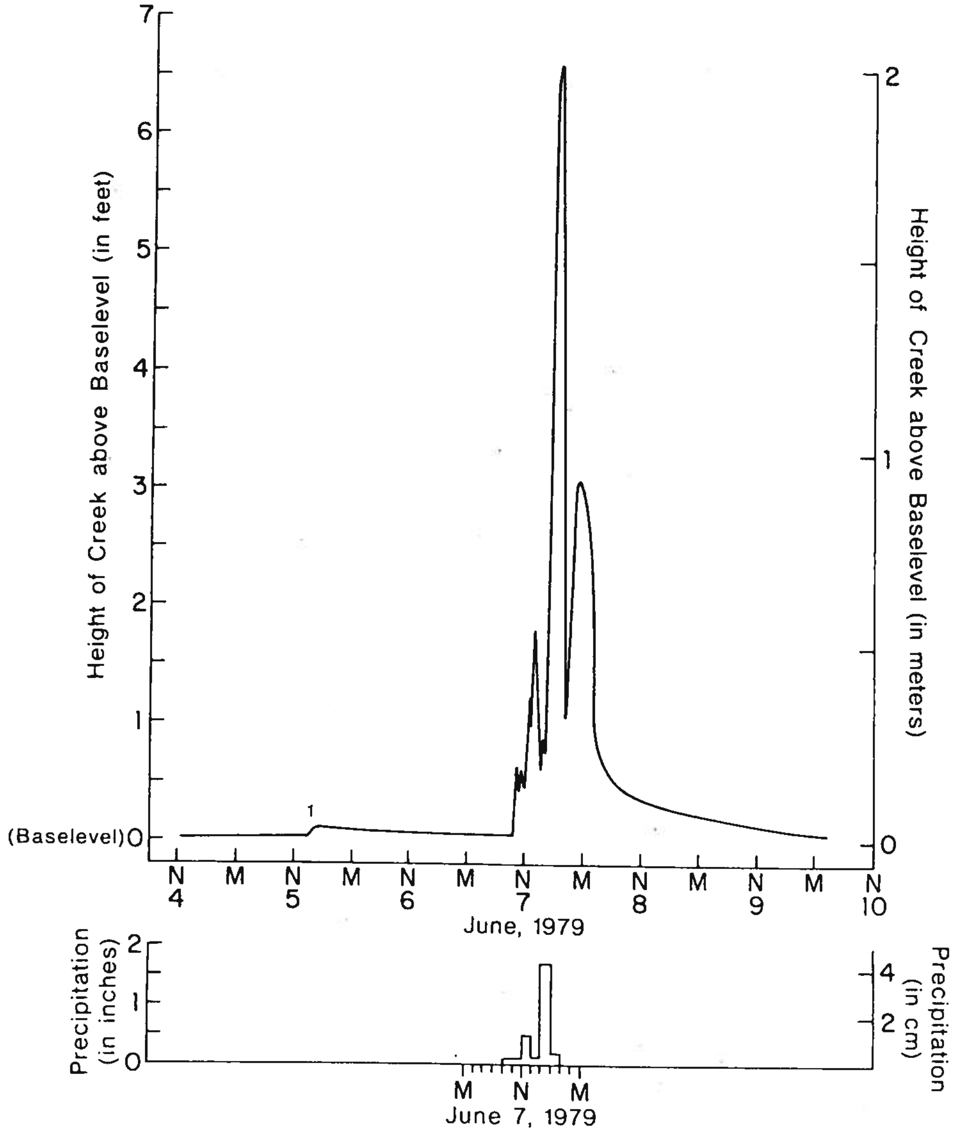


Fig. 4. Arcadia Creek at gaging site under baseflow conditions (around 0.2 cms). The Stevens F-type level recorder is housed in the box.

period of precipitation (4–6 p.m.) was measured at 4.3 cm. This is near the 5-year recurrence rainfall of 4.8 cm in 2 hours.

The stream response at the gage to heavy precipitation was very rapid, producing a kurtosic rise in the height of the stream followed by an equally sharp recession (Fig. 5). The maximum height (2.0 m above baseflow level of 0.4 m) occurred shortly after 6:00 p.m. (Fig. 6). The "spike" recorded on the graph indicates a response different from that expected from a basin of 1,774 ha which would be expected to have a more gradual and prolonged rise and retreat. A second indicator uncharacteristic of a basin of this size is the long period necessary to return to baseflow conditions. Approximately 36 hours passed before the stream height stabilized.



[1] Rise is attributable to basin precipitation so slight that it did not register on the recording rain gage.

Fig. 5. Stage-height recording of Arcadia Creek gage and associated 2-hour precipitation events (precipitation date from NOAA; creek data from field observations).

Although direct measurement of discharge was not possible, indirect methods indicate a peak flow at the gage of around 8.1 cms. This is far below the 19.8 cms estimated via the rational method. It is true the storm assumed for the rational method calculation was a 3-hour event whereas the storm evaluated was 2 hours. However,

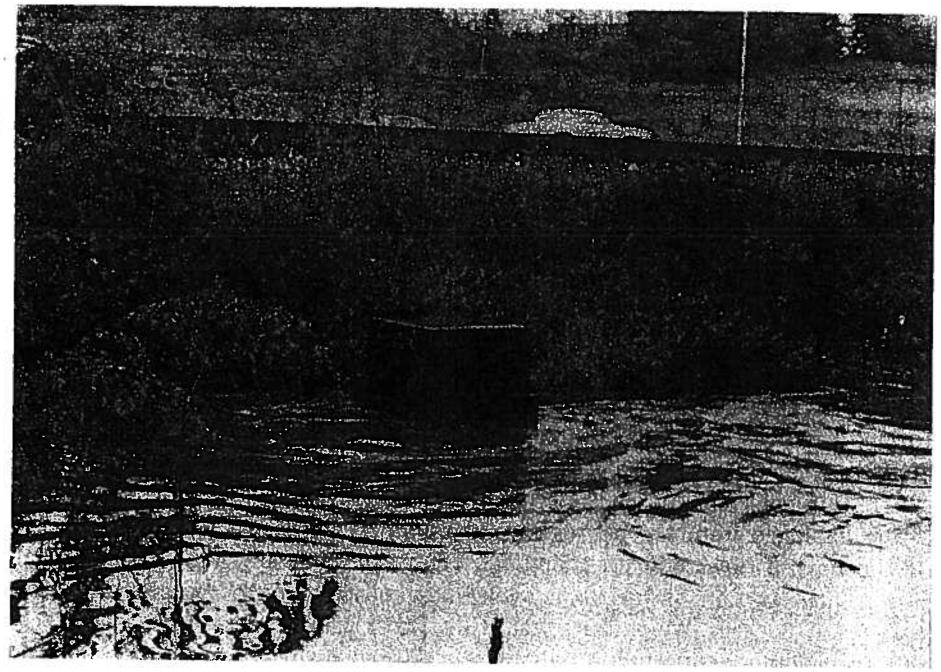


Fig. 6. Arcadia Creek at gaging point under flood conditions of June 7, 1979. Water level is 2.0 meters above baseflow level and discharge is estimated to be 6.0 cms.

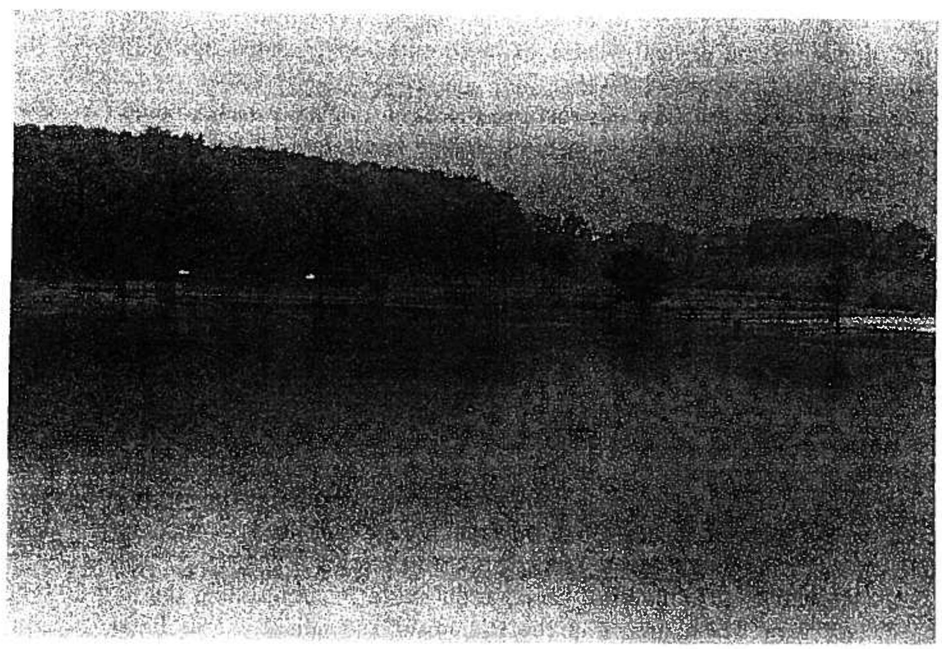


Fig. 7. Ponding behind culvert constriction at Christian School after the storm of June 7, 1979. Water accumulates on grassy area and athletic facilities.

considering that the totals (5.3 cm for the theoretical storm and 4.3 cm for the actual) were reasonably close and the actual event had a higher intensity (2.2 cm per hour vs. 1.8 cm per hour), promoting rapid runoff, such a large difference between estimated and measured runoff is improbable.

The explanation for the storm response pattern and the unexpectedly low discharge is that channel, closed depression, swamp, and retention basin and groundwater recharge as well as obstructions are critical mechanisms both reducing expected downstream flow and diminishing the area contributing significantly to discharge at the gaging point. At Christian School, for example, Arcadia Creek flows beneath Howard Street (1.5 km upstream from the gage) in a 183 cm corrugated metal pipe. The conveyance capacity of this culvert is 3.5 cms. However, the upper opening has been restricted by a control structure to a rectangular aperture 1.2 m by 0.5 m (0.6 m^2) with a calculated maximum discharge of around 1.0 cms (Hulsing, 1967). Thus, unless sufficient water accumulates to overflow Howard Street, downstream discharge from the basin above this point is restricted to the latter value. Overflooding of Howard Street is unusual. Thus, expecting very heavy and rare rains, only a small portion of the basin contributes substantially to the discharge being measured at the gage. We estimate that of the 1,774 ha in our study area, only 400 ha (23%) contribute meaningfully to discharge measured at the gage during large storms. The 1,376 ha of basin above Christian School are limited to a maximum contribution of no more than 1.0 cms.

The limited part of the basin contributing most of the flow at the measuring point also accounts for the shape of the hydrograph. Surface runoff from this significantly urbanized tract with some areas of moderate slope is heavy and rapid, causing a quick stream rise and rapid recession. The long period required for a return to baseflow is due to the gradual release of stormwater accumulated upstream from the constriction at Christian School (Fig. 7).

Upstream from the flow obstruction, the basin originally had a number of low, swampy areas which served as natural storage and retention basins during storms. These are clearly discernible on the 1916 15-Minute Kalamazoo topographic map. Swamps and marshes along the main channel in 1938 and 1950 are estimated at nearly 81 ha and were obviously capable of storing much runoff. Accumulated water would subsequently be released downstream. The net effect was to cut the peaks off of storm hydrographs.

Analysis of aerial photography for 1964 and 1974 and field observations reveal that most of the largest marsh has been converted to a 7-ha retention pond or filled in for trailer parks. Other swamps, lowlands, and closed depressions have been coverted to (or become) perennial ponds. Parking lots now occupy some former wetlands. In spite of these actions, marshes remain. Along with the retention basins and other ponds (a number of which have been inadvertently created as the result of highway construction), a large volume of stormwater storage capacity still exists in the upper part of the basin and still acts to reduce peak storm flows.

Unfortunately, little political cooperation exists for controlling the rate or type of development which occurs in the floodplain and adjacent area of the stream. Three political units (one city—Kalamazoo—and two townships—Kalamazoo and Oshtemo) govern land use in the Arcadia Creek basin and they each have separate zoning for the portion of the basin under their jurisdiction. Current zoning allows

Table 2. Estimated Percentage of Basin Runoff Retained in Storage

Date	Return period storm			
	5-year	10-year	50-year	100-year
1964	50	57	61	64
1974	59	62	65	67

for both residential and commercial development of areas adjacent to the stream which threatens to eliminate remaining natural storage while increasing the impervious area and stormwater runoff.

Estimates of the percentage of basin runoff held in storage for 1964 and 1974 for different storm events are given in Table 2. It should be noted that the percentage of runoff held in storage is rising as increased urbanization leads to more runoff and less infiltration. Flow at the gage site is significantly reduced by upstream storage (see Fig. 3). Along with the effect of the Christian School culvert blockage, we estimate that the 1974 discharge for a 5-year storm would have been only 8.1 cms (59% less than that calculated via the rational formula) whereas 100-year event would be reduced to 17.1 cms, a 67% drop (Table 3). As mentioned earlier, indirect methods for determining the discharge at culverts indicate the peak flow at our gage for the June 7, 1979 storm, which was close to a 5-year storm, was around 6.0 cms. There was considerable storage on an adjacent parking lot and field, which if added to this figure would bring it closer to the value of 8.1 cms established by our adjustment to the flows derived via the rational method.

FLOODING ON THE LOWER CHANNEL

Even though much of the increase in runoff induced by urbanization within the study area is retained in storage and does not contribute to downstream peak discharge, flooding problems have grown in recent years. In April, 1975, a storm with a recurrence interval of 25 years produced 7.6 cm in 5 hours in the Kalamazoo area (NOAA, 1975). Arcadia Creek flooded several places in the downtown area and caused considerable damage. One of the older culverts in which the creek flowed exploded from excessive hydraulic pressure (Fig. 8). It cost the city $85,000 to repair the damage done by the storm.

Table 3. Estimated Runoff (cms) Relationships for Arcadia Creek, 1974

Return period for 3-hour storm	Basin peak runoff	—	Peak discharge at gage	=	Basin storage	Percentage of runoff in storage
5	19.8	—	8.1	=	11.7	59.2
10	27.2	—	10.3	=	16.9	62.2
50	40.3	—	14.2	=	26.1	64.6
100	51.1	—	17.1	=	34.0	66.5

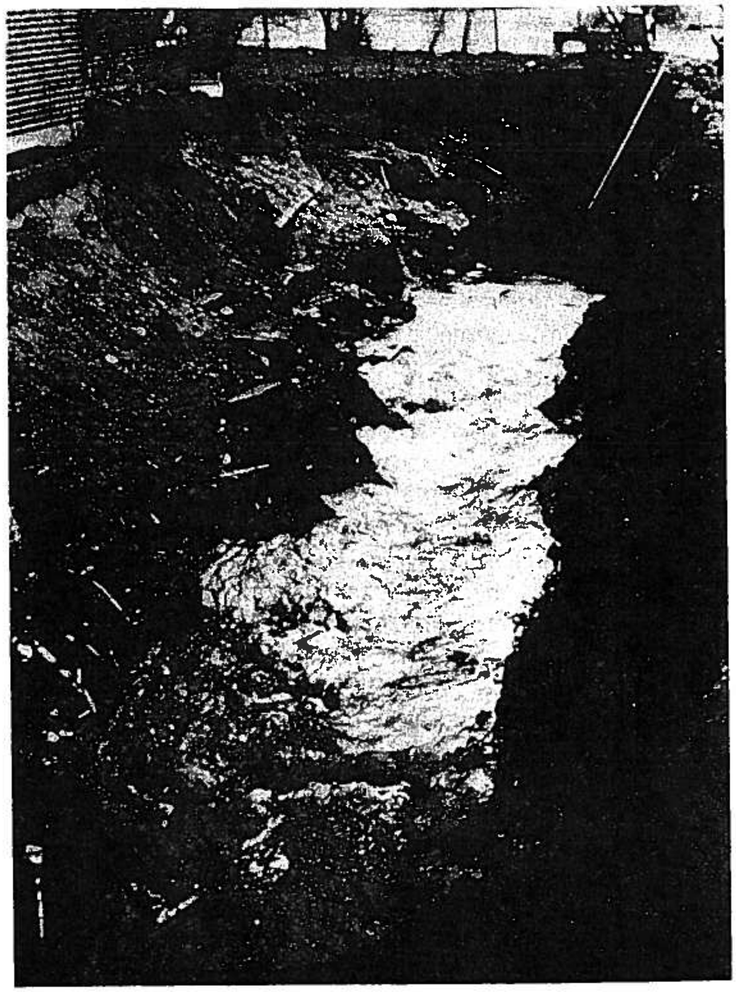


Fig. 8. Once enclosed culvert in which Arcadia Creek flowed after exploding as a result of excessive hydraulic pressure. (Photograph courtesy of Walter Jones, City of Kalamazoo.)

In June, 1978, a storm generated 13.0 cm in a 12-hour period (NOAA, 1978). This event was slightly greater than a 100-year storm. The most intense hour and 2-hour falls were almost the same as in 1975 (3.3 cm and 4.1 cm). But, the constrictive downstream culvert had been replaced with a larger structure. Consequently, the storm caused less flooding and damage than the 1975 event.

The most intense rainfall in recent memory (10.2 cm in 4 hours—well above the 100-year storm) struck Kalamazoo on June 17, 1982. It caused flooding of Arcadia Creek in the downtown area characteristic of the earlier storms. The storm also caused overflooding of Howard Street at Christian School where discharge is restricted by a control structure at the head of the culvert.

A 1976 study of storm drainage problems in Kalamazoo estimated that the cost of correcting current and anticipated flooding problems along Arcadia Creek would be well over $6.5 million (Jones and Henry Engineers, 1976). That study suggested a mixture of traditional and more modern means of dealing with stormwater drainage. Thus, measures were proposed to increase the capacity of the channel to convey peak flows to downstream areas (basically installing larger culverts and pipes) along with provisions for temporary storage of surface runoff in retention basins and natural areas to reduce peak flows.

The potential for flooding could increase markedly as urbanization intensifies in Arcadia Creek basin. The pervious surface area will decrease and the sewered area increase. These changes will lead not only to more surface runoff during a given storm but to reduced lag-time and time of concentration, contributing to much greater peak flows. Additionally, continued development along the stream channel will reduce the area of natural storage. As a consequence, artificial retention in the upper portion of the basin which is now capable of handling even the largest storms may be overwhelmed by the increased volume of runoff generated as a result of these land-use changes. In turn, this would mean much greater downstream discharge and flooding problems along the channel generally and particularly in the downtown area.

CONCLUSIONS AND RECOMMENDATIONS

Arcadia Creek is a typical small watershed experiencing the impacts of urban development. Runoff has increased as more of the basin has been transformed from pervious to impervious surfaces. Peak storm flows, however, have been less than expected because of a combination of natural and artificial storage and channel obstructions that retard flow. Indeed, these factors have effectively separated the basin into several hydraulic units, each with its own peak flow response to storms which is related to the physical nature of the contributing area (size, surface character, slope, etc.). These units are, for the most part, connected by culverts and pipes which act as controls of the volume of water delivered downstream. With further urbanization, downstream discharge and flooding could greatly increase as basin runoff increases and natural and artificial controls lose their effectiveness. The installation of storm sewers lessen the time of concentration and lag-time producing a more instantaneous response of the stream to precipitation. As natural retention areas are lost to development, the potential increases for overwhelming those systems for stormwater storage.

Methods for both controlling and preventing stormwater discharge are needed for an effective solution to the problem. The single approach of increasing downstream conveyance via channel work or increasing culvert size is ineffective. The solution lies in both structural and policy approaches. Structural modifications within the basin could include strategically sited infiltration and retention basins constructed by local agencies. Private landowners could be required to provide on-site runoff control through the use of small retention ponds, rooftop detention, porous pavements, and parking lot detention. Such measures would contribute markedly to retarding surface runoff and decreasing downstream discharge.

Policy decisions would require the cooperative efforts of all political units governing the watershed. In the case of Arcadia Creek, the two township governments and the city must adopt similar zoning controls over the basin which are aimed at preserving areas and maintaining natural storage along the floodplain. The entire floodplain should be surveyed to identify areas of inadvertent temporary stormwater storage such as parking lots and athletic fields. Our study found them to be important in reducing peak flows and this function should be maintained and enhanced. Furthermore, it can be argued that outside the downtown area where flooding causes serious damage, "undersized" culverts, as a rule, should not be replaced with larger structures. These perform a valuable flow retardation function during storms. Flooding from this is temporary (several hours at most) and in almost all cases limited to natural areas, fields, parking lots, or roadways. Lasting damage is minimal. Also, this approach largely eliminates expensive large-scale reconstruction of the channel. Finally, modification of the upstream portion of the basin must be monitored so that changes in the channel or adjacent floodplain that could increase downstream storm flow are avoided or minimized. A combined program of structural modifications and policy decisions along the lines suggested is the most effective and least cost means of dealing with stormwater problems arising from urbanization.

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BIBLIOGRAPHY

Abrams Aerial Survey Corp. (1938, 1950, 1964, and 1974) Aerial photographs of Kalamazoo, Michigan. Lansing, Michigan.

Bodhaine, G. L. (1968) Measurements of peak discharge at culverts by indirect methods. Techniques of Water Resources Investigations of the U.S. Geological Survey, Chapter A3, Book 3: *Applications of Hydraulics.*

Coder, Thomas C. (1978) *Analysis of land use change on discharge in a small drainage basin—Arcadia Creek.* Unpublished master's degree paper. Department of Geography, Western Michigan University, Kalamazoo.

Chow, Ven Te (1974) *Handbook of Applied Hydrology: A Compendium of Water Resources Technology.* New York: McGraw-Hill.

Gray, Donald M., ed. (1973) *Handbook on the Principles of Hydrology* (reprinted). Huntington, NY: Water Information Center, Inc.

Hulsing, Harry (1967) Measurements of peak discharge at dams by indirect methods. Techniques of Water Resources Investigations of the U.S. Geological Survey, Chapter A5, Book 3: *Applications of Hydraulics.*

Jones and Henry Engineers Limited (1976) *Master Plan of Storm Drainage for the City of Kalamazoo, Michigan.* Toledo, Ohio, 139 pp.

Leopold, Luna (1968) *Hydrology for Urban Land Use Planning—A Guidebook on the Hydrologic Effects of Urban Land Use.* Washington, DC: U.S. Geological Survey Circular 554.

NOAA (1975) *Hourly Precipitation Data: Michigan.* Vol. 25, No. 4 (April), p. 7.

_______ (1978) *Hourly Precipitation Data: Michigan.* Vol. 28, No. 6 (June), p. 7.

_______ (1979) *Hourly Precipitation Data: Michigan.* Vol. 29, No. 6 (June), p. 8.

Stephenson, D. (1981) *Stormwater Hydrology and Drainage.* Amsterdam: Elsevier Scientific Publishing Co.

Urban Drainage Subcommittee (1977) *Manual of Practice on Urban Drainage* (draft no. 3). Ontario Ministry of the Environment, Toronto, pp. 3-12 to 3-15.