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LIMEKILN SLOUGH DRAINAGE, PULASKI COUNTY, ILLINOIS

by
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INTRODUCTION

Limekiln Slough is a tributary of the Cache River in the Buttonland Swamp area in extreme southern Illinois (figure 1). The watershed was originally wooded with much of the area existing as wetlands, but it is now predominantly agricultural. The lower portion of Limekiln Slough, upstream of Perks Road, has been channelized to provide better drainage, though areas upstream of this road have continued to experience flooding (Big Creek Drainage Commission, personal communication, 1986). In order to reduce the flooding in the area, the Big Creek Drainage Commission has proposed installing an additional culvert under Perks Road.

Objections over the placement of an additional culvert have been raised by groups and persons concerned about the integrity of Buttonland Swamp. These objections stem from the possible adverse impacts on the Buttonland Swamp area. The main concern is that the more efficient drainage would transport more sediment into the wetlands. Presently, this sediment is deposited en route. Little information and data are available concerning the hydrology of the watershed and the hydraulics of the culverts. Therefore, the purpose of this study was to gather information to make possible the assessment of the impacts of the installation of an additional culvert under Perks Road.

Background

Drainage for agriculture in the Cache River basin has been a problem since the area was settled in the 1800's. The flat slope of the lower Cache River along with the backwater effects of the Mississippi River have contributed to poor drainage along the lower Cache River channel and its floodplain. Many attempts have been made to improve drainage in the lower Cache River basin.

An ambitious attempt to improve drainage within the Cache River basin was the construction of the Post Creek Cutoff by the Cache River Drainage District in 1915. Post Creek originally flowed north into the Cache River, but the gradient of Post Creek was reversed so it would flow south into the

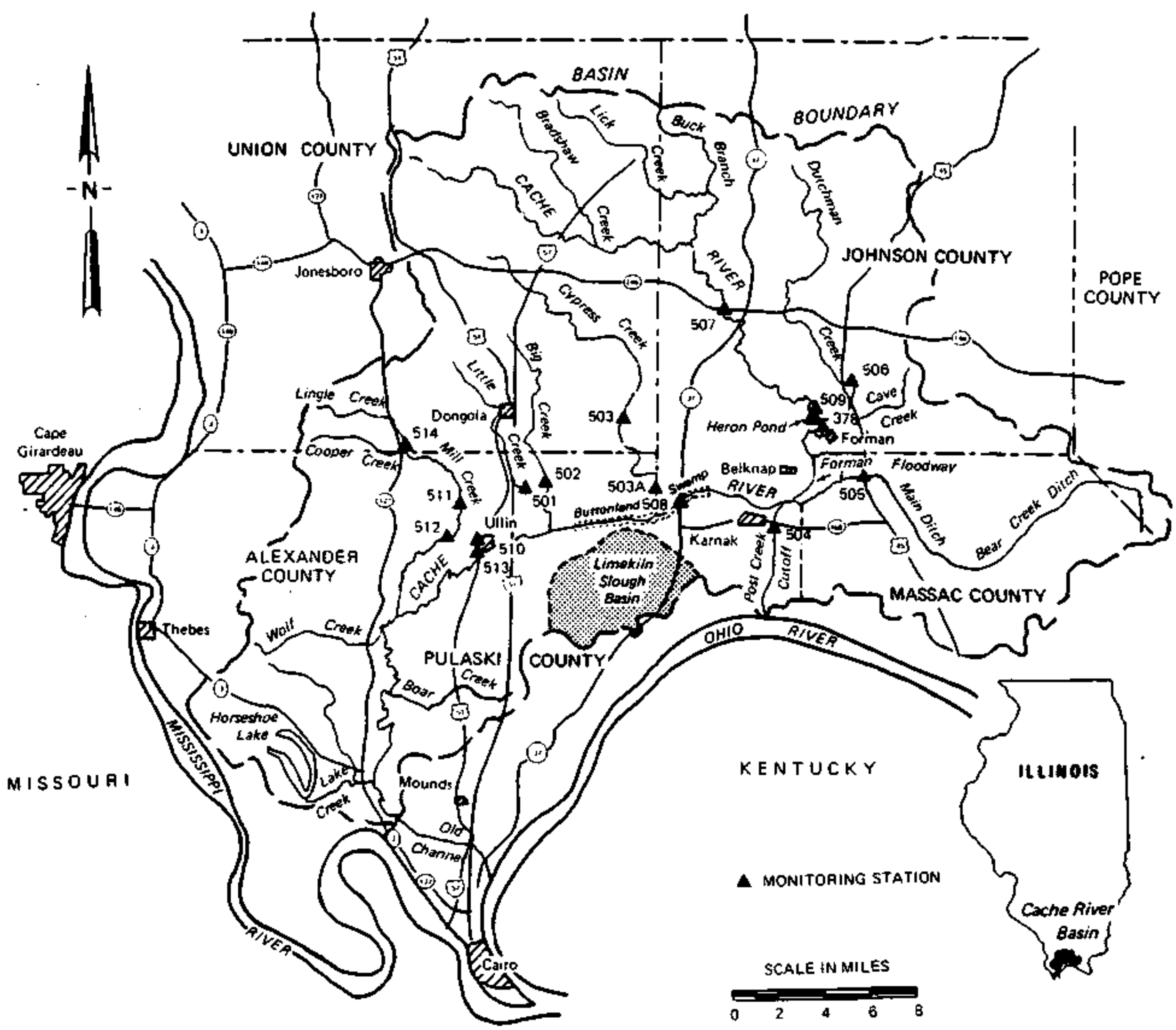


Figure 1. Location of the Limekiln Slough basin in the Cache River watershed

Ohio River. All of the drainage from the upper Cache River basin was diverted through the Post Creek Cutoff by the construction of a continuous spoil bank formed from the dredge material along portions of the Forman Floodway and the Post Creek Cutoff. This action divided the Cache River basin nearly in half, with 373 square miles of the watershed draining into the Post Creek Cutoff and 365 square miles draining into the lower Cache River basin. Although the construction of the Post Creek Cutoff may have improved drainage in the upper Cache River basin, most of the present problems in the upper Cache River basin and the Buttonland Swamp area can be attributed largely to the construction of this channel (Demissie and Bhowmik, 1985).

Project Description

Limekiln Slough passes under Perks Road through four 6-foot culverts and drains into the Cache River through Buttonland Swamp. The area downstream of Perks Road is mostly wetland and is heavily wooded, and the channel lacks definition. Upstream of Perks Road, there is a well defined channel although there is occasional flooding which is attributed to the inadequate capacity of the culverts. To alleviate this flooding, the Pulaski County Highway Department plans to install an additional 8-foot-diameter culvert requested by the Big Creek Drainage Commission. The primary focus of this report will be to evaluate the possible impacts of the additional culvert on flooding and sedimentation upstream and downstream of the culverts under Perks Road.

HYDROLOGIC AND HYDRAULIC ANALYSIS

Watershed Hydrology

Watershed Description

The watershed information was gathered mostly from the U.S. Geological Survey's (USGS) 7.5-minute maps (Cypress and Olmstead quads). As indicated by these maps, Limekiln Slough runs north for 3.5 miles from the basin boundary and then proceeds in a northeasterly direction up to the vicinity of the culverts under Perks Road. The drainage area of Limekiln Slough at the culverts is approximately 20 square miles. From this point on the stream meanders northwest to its confluence with the Cache River.

The confluence, as shown on the USGS maps, is approximately 2000 feet east of Cache Chapel Road. Figure 2 provides a map of the watershed. Since the actual location is not clearly defined in the field, the location as presented on the USGS maps will be used for discussion.

The overall length of the stream from the basin divide to the confluence with the Cache River is 51,000 feet or almost 10 miles. The drop in elevation from the watershed divide to its confluence with the Cache River is about 150 feet. The profile of the stream may be seen in figure 3. The water surface on 12 December 1985 is also shown on this figure. Most of the drop in elevation (over 100 feet) occurs in the upper reaches of the stream in the vicinity of the basin boundary. The USGS maps compiled in 1966 show Limekiln Slough and its tributaries leaving the upland areas to drain into several wetland areas known as Brushy Swamp. Most of the Brushy Swamp area is at an elevation of 340 feet msl (mean sea level). From the Brushy Swamp area there is approximately a 10-foot drop in elevation to the culverts under Perks Road. Since the USGS maps were prepared in 1966, most of Brushy Swamp has been cleared and drained for agricultural uses. The Brushy Swamp area existed due to depressions in the topography and poorly drained bottomland soils. These areas, now in agriculture, suffer from poor drainage and some flooding.

To further illustrate the topography of the Limekiln Slough watershed, a hypsometric curve was prepared and is presented in figure 4. The hypsometric curve shows the percentage of the area that exists above mean sea level (msl). The curve clearly shows the flat topography that exists in the lower elevations of the Limekiln watershed. In fact, 50 percent of the watershed area lies below 340 feet msl, though there are areas in the watershed at an elevation of 480 feet msl.

Clearing of the Brushy Swamp area and improvement of the drainage through channelization most probably resulted in decreased attenuation of the flood peak of Limekiln Slough. This clearing and improved drainage causes more water to arrive at the culverts more quickly, exacerbating the flooding problems in the downstream reaches of the stream. The impacts on flooding caused by improved drainage by channelization and draining of wetlands for agricultural and other uses can be demonstrated by figure 5 (Chow, 1959). The two hydrographs shown in this figure are for conditions before and after drainage improvements and clearing. Under natural

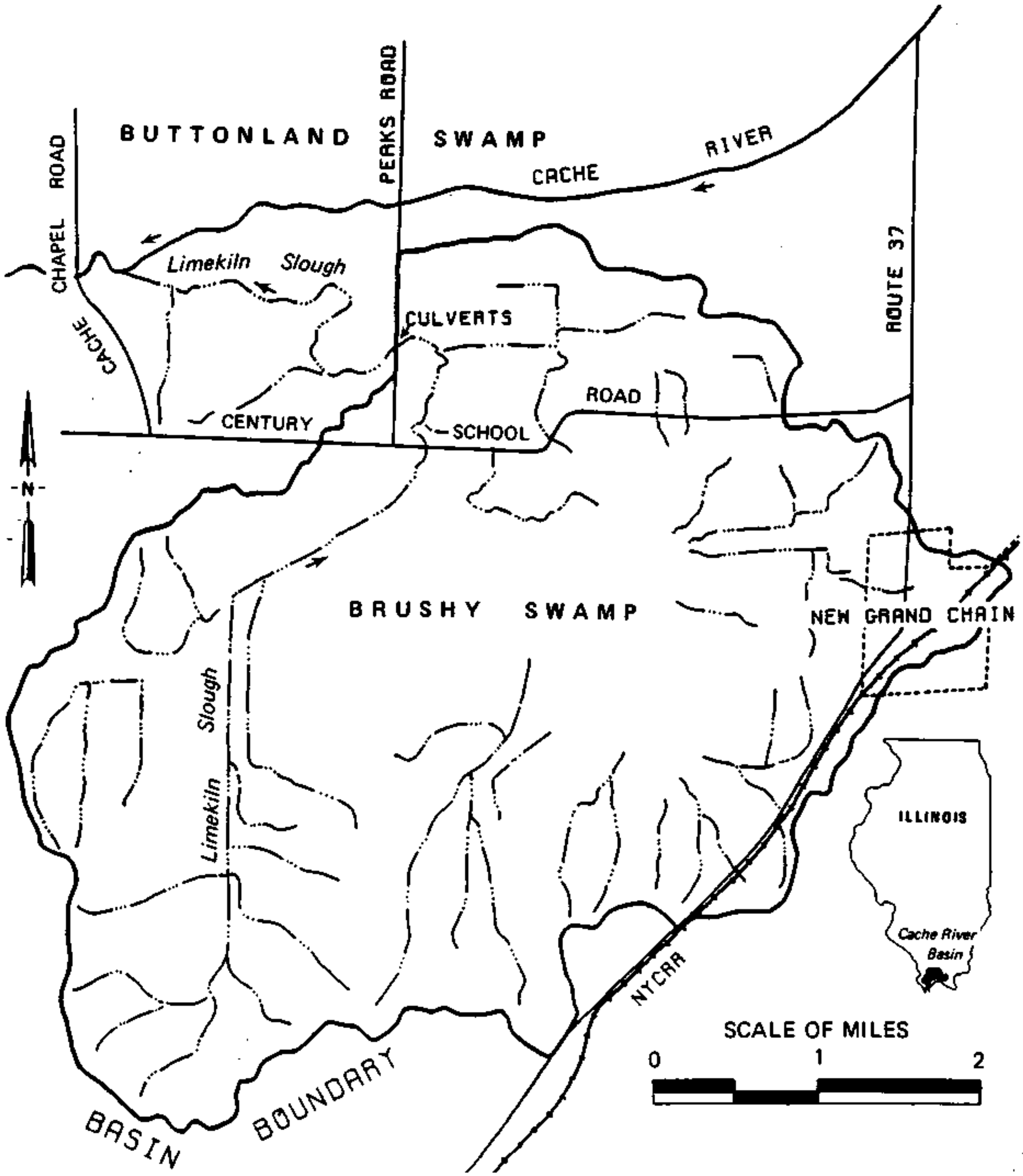


Figure 2. Limekiln Slough basin

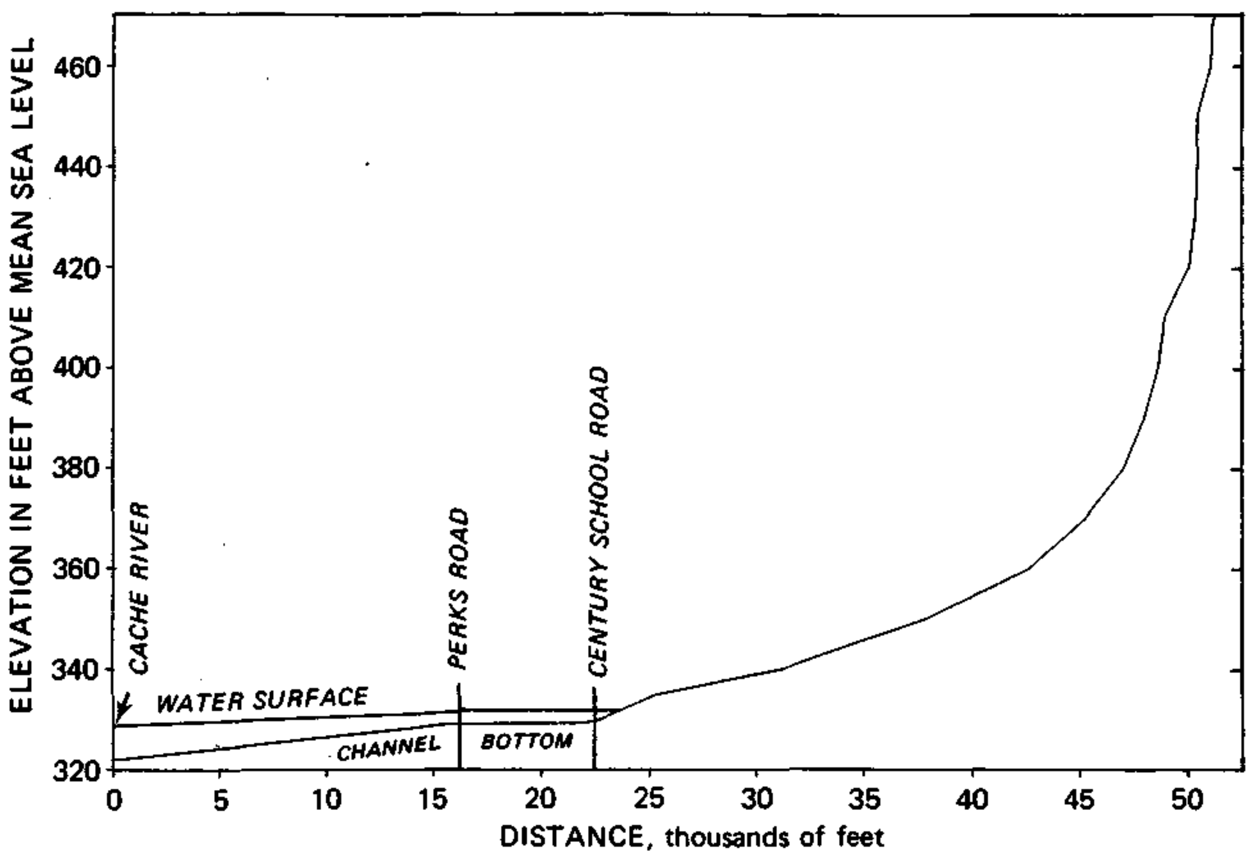


Figure 3. Stream distance along Limekiln Slough above the confluence with the Cache River

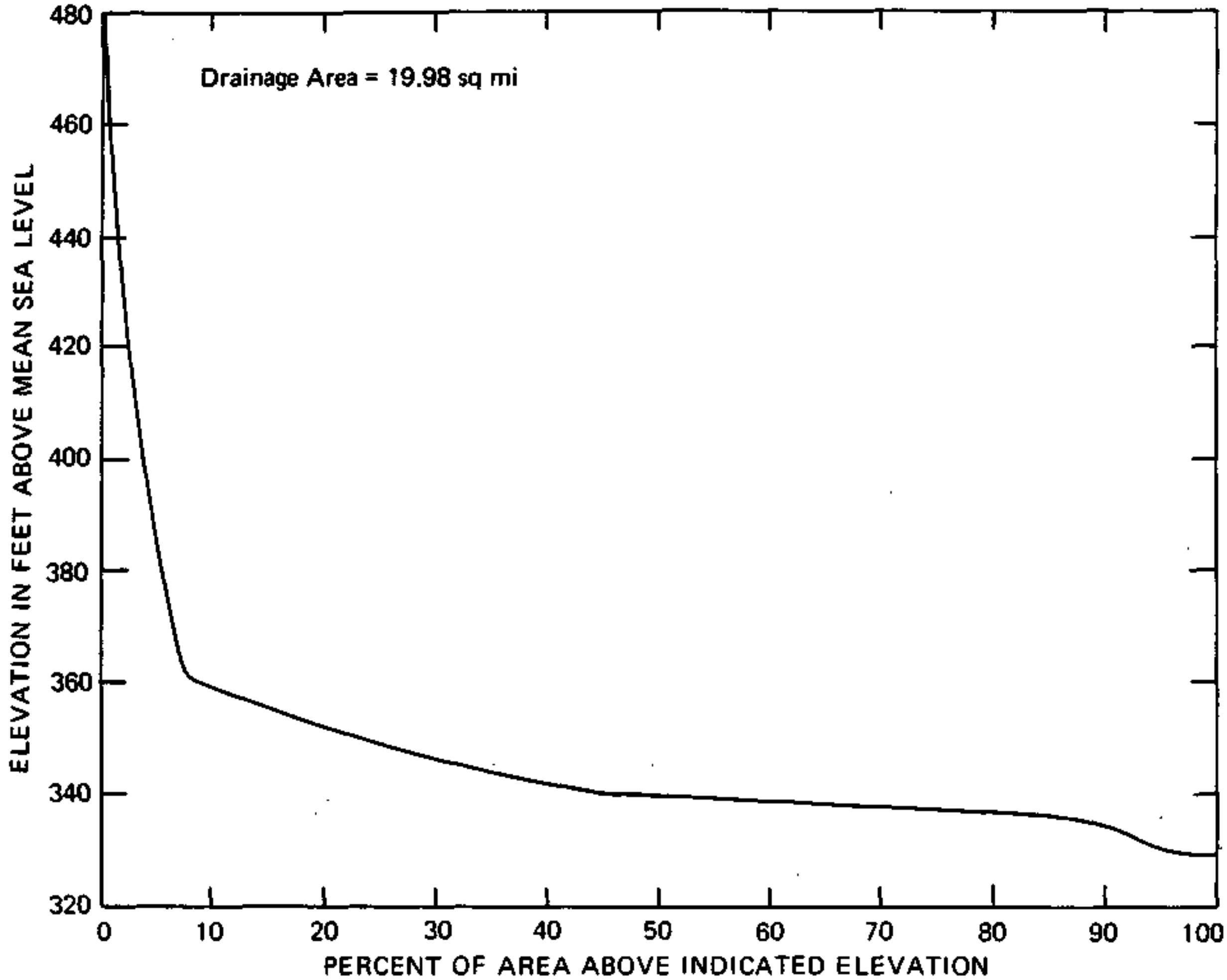


Figure 4. Hypsometric curve for the Limekiln Slough watershed

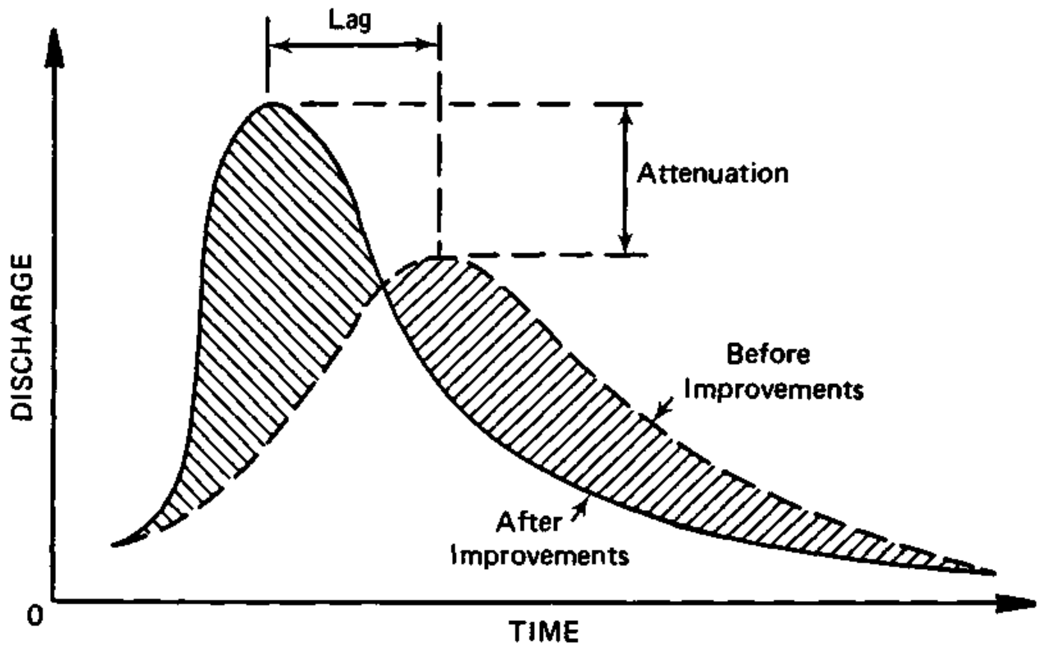


Figure 5. Decreased attenuation and lag in flood flow due to increased hydrologic efficiency in the watershed (after Chow, 1959)

conditions wetlands provide significant storage for storm runoff. Stream channels with natural vegetation and obstructions are not as efficient as drainage ditches in carrying flood flows, resulting in a slow and gradual movement of floodwaters downstream. As a consequence, flood peaks under natural conditions are smaller than under improved drainage conditions even when the total amount of runoff is the same under both conditions.

Improvements in drainage have benefits and disadvantages. The benefits are improved drainage in the upper reaches of the watershed where the floodwaters are conveyed more rapidly out of the area, resulting in less flooding. On the other hand, the downstream reaches will experience higher flood peaks and thus increased flooding. Existing drainage structures such as culverts and ditches in the downstream reaches might not be able to pass the increased flows and thus might create additional flooding problems.

Land use changes from wetland to agriculture through drainage improvements also result in increased erosion in the uplands and increased sedimentation in the stream channels downstream. Sedimentation in stream channels and drainage ditches decreases their flow carrying capacity, which might also result in increased flooding.

Hydrologic Concepts

The discharge in a stream is governed primarily by precipitation. A portion of the precipitation that falls may be lost to interception, evapotranspiration, depression storage, and infiltration. The portion of the precipitation which is not lost enters the stream as runoff. The quantity of runoff from a precipitation event depends on a number of factors including the moisture condition of the watershed at the onset of the event and the characteristics of the precipitation, such as the rainfall amount, intensity, and duration (Linsley et al., 1975).

To describe the quantity of runoff, probability analysis is used. Probability analysis defines the flood-peak magnitude with exceedance probability or recurrence interval. Exceedance probability is the chance that a flood of a given magnitude will be equaled or exceeded in any year. The recurrence interval is the reciprocal of exceedance probability and describes the return period of a flood. For example, a flood with a 10-year recurrence interval is expected to take place once every 10 years, on the average. However, a flood of a given recurrence interval may actually recur in a much shorter period of time, such as successive weeks or months (Curtis, 1977).

Peak Flows from the Watershed

Since no streamflow data are available for Limekiln Slough, the magnitudes of floods of various recurrence intervals were computed on the basis of methodology given by Curtis (1977). This method was derived from a multiple regression analysis of streamflow and basin characteristics of 241 watersheds in Illinois, Indiana, and Wisconsin. The regression analysis indicated that the independent variables of drainage area, main channel slope, rainfall intensity, and an areal factor are the most significant variables of the estimation of peak discharge for streams in Illinois. The areal factor accounts for the variations in the runoff characteristics of different regions in the state. This method does not take into account land use changes that can occur on a watershed and the resulting changes in flood peaks that might occur.

The following equations were used to compute the peak flows:

$$Q_2 = 42.7 \cdot A^{0.776} \cdot S^{0.466} \cdot (I-2.5)^{0.834} \cdot Af$$
$$Q_5 = 71.1 \cdot A^{0.769} \cdot S^{0.485} \cdot (I-2.5)^{0.833} \cdot Af$$
$$Q_{10} = 90.8 \cdot A^{0.767} \cdot S^{0.494} \cdot (I-2.5)^{0.833} \cdot Af$$

where: Q_2 = 2-year flood magnitude, cubic feet per second (cfs)
Q_5 = 5-year flood magnitude, cfs
Q_{10} = 10-year flood magnitude, cfs
A = drainage area, square miles
S = main channel slope, feet per mile
I = 24-hour rainfall, inches
Af = areal factor

The parameters used for the Limekiln Slough watershed were: drainage area - 19.98 square miles, main channel slope - 9.11 feet per mile, 24-hour rainfall - 3.60 inches, and areal factor - 0.87. On the basis of these parameters, the following peak discharges were calculated for 2-, 5-, and 10-year flood recurrence intervals:

Recurrence interval (yrs)	Discharge (cfs)
2	1150
5	1960
10	2530

Culvert Hydraulics

Culvert Description

Presently there are four 6-foot culverts to convey the flow in Limekiln Slough under Perks Road. Plans are to place an additional 8-foot-diameter culvert under the road. All existing culverts are constructed of corrugated metal, as is the supplemental pipe. The existing 6-foot pipes are 50.5 feet long. The upstream and downstream invert elevations as well as the slopes are presented in table 1. The invert is the bottom of the culvert, while the crown is the top. Three of the culverts were placed at a negative (adverse) slope and one was placed at a horizontal slope; these are not the most efficient configurations for drainage purposes. The information used in the discussion of the culverts was obtained through a field survey of the area. Design figures or discussions of the culverts were not available from any source.

Figure 6 is a photograph showing the upstream end of the culverts, looking in the northwest direction. Note the debris restricting the flow through the culverts. Figures 7 and 8 are upstream (east) and downstream (west) views photographed from the top of the culverts at Perks Road. On two separate visits the head loss, which is the difference in the water surface elevations between the upstream and downstream ends of the culverts, was 0.5 feet. This was mainly due to debris impeding flow through the culverts and not to the limitation of the existing culverts in conveying flow. The upstream water surface was at an elevation of 332.0

Table 1. Characteristics of the Existing Culverts under Perks Road

Culvert	Upstream invert elevation (ft.msl)	Downstream invert elevation (ft.msl)	Slope (ft/ft)
North 1	329.5	329.7	-0.00277
2	329.4	329.4	0.00000
3	329.1	329.3	-0.00297
South 4	329.1	329.2	-0.00237

Figure 6. Limekiln Slough culverts under Perks Road, looking northwest

Figure 7. Limekiln Slough upstream (east) of the culverts under Perks Road

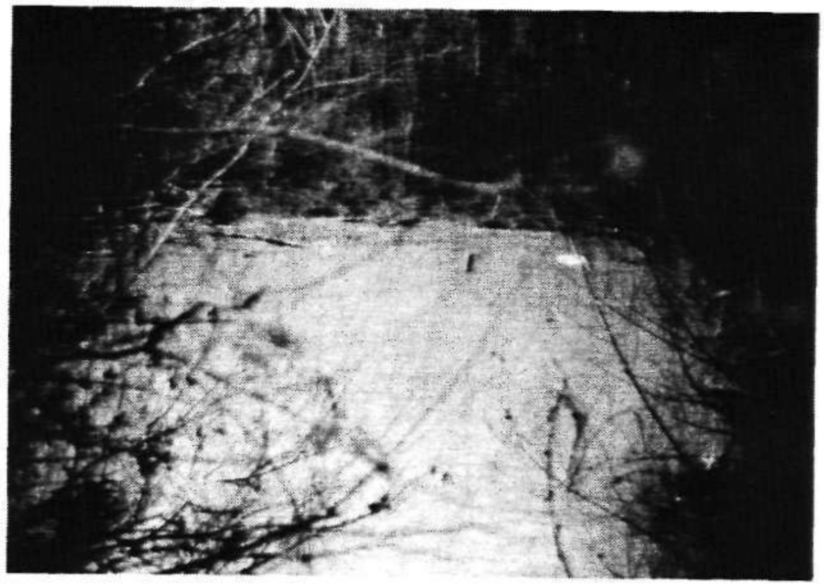


Figure 8. Limekiln Slough downstream (west) of the culverts under Perks Road

feet msl while the downstream elevation was 331.7 feet msl on 12 December 1985. The corresponding water surface elevation in the Cache River at the Perks Road bridge was 329.1 feet msl. Therefore, the drop in the water surface between the culverts and the Cache River was approximately 2.6 feet. The survey found that the thalweg, the deepest portion of the stream channel, in the Cache River at the Perks Road bridge was 322.0 feet msl. Another survey (Bryan, 1982) also found that the thalweg elevation of the Cache River was 322 feet msl in the vicinity of the confluence of Limekiln Slough with the Cache River. These thalweg elevations, as well as the water surface of the Cache River mentioned earlier, are presented on figure 3.

It was determined from a survey of Limekiln Slough and the Perks Road area that the low elevation at Perks Road was approximately 336.6 feet msl. This is the level at which water would begin to flow over the road. Therefore, the water level upstream of Perks Road can reach 7.2 feet above the inverts of the culverts before the road is overtopped. A recent (December 1985) high water mark upstream of Perks Road was found to be 335.3 feet msl, which is 1.3 feet below the point where overtopping of the road would occur.

The conditions in the area of the culverts on 12 December 1985, when the upstream water surface was 332.0 feet msl, were such that 100 to 200 feet of surrounding fields were flooded on each side of the channel. This flooding extended from the culverts to Century School Road. Scattered flooding was also observed in the Brushy Swamp area over an area ranging in size from 1 to 20 acres. According to figure 4, 8 percent of the watershed would be flooded when the water level upstream of the culverts is at an elevation of 332 feet msl. Flow conditions at the culverts on this visit were such that the three northern culverts were partially blocked and the southernmost culvert was carrying most of the flow. On the 16 December 1985 visit the water level was about 1 foot lower (331 feet msl) than on the previous visit. There was no field flooding though the stage was at bank full. Below the culverts no definite channel was observed. This area appears to be wetlands with thick stands of mesic species: gum, cypress, oak, willow, and button brush. There was occasional open water but with no measurable surface velocity.

Hydraulic Concepts

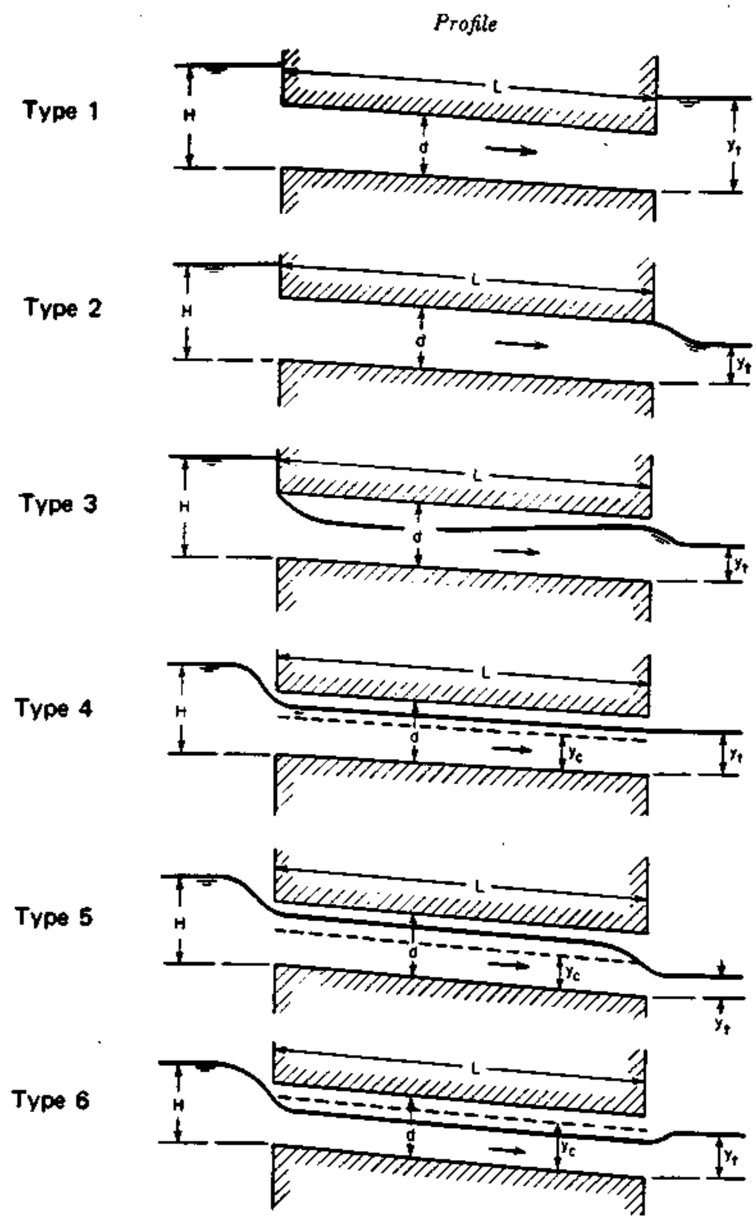
The flow through a culvert is influenced by the difference in the upstream and downstream water surface elevations. However, the hydraulics of a culvert are complicated by the many variables that control the flow such as the culvert's inlet geometry, slope, shape, and roughness, and the approach and tailwater conditions (Chow, 1959). The flow in culverts is classified as either inlet or outlet control. Inlet control is dependent only on the upstream conditions such as headwater depth and inlet geometry. With outlet control the roughness, the length of the culvert barrel, the inlet geometry, the outlet geometry, the headwater depth, and the tailwater depth are factors in determining the flow carrying capacity.

The outlet and inlet conditions are subclassified into six types of culvert flow according to the following outline also seen in figure 9 (Chow, 1959):

- I. Outlet submerged . . . . Type 1
- II. Outlet unsubmerged
  - A. Headwater greater than the critical value
    - 1. Culvert hydraulically long . . . . Type 2
    - 2. Culvert hydraulically short . . . . Type 3
  - B. Headwater less than the critical value
    - 1. Tailwater higher than the critical depth. . Type 4
    - 2. Tailwater lower than the critical depth
      - a. Flow subcritical . . . . Type 5
      - b. Flow supercritical . . . . Type 6

An explanation of some of the terms follows. A culvert which is hydraulically long is of sufficient length to allow the expanding depth of flow below the entrance to rise and fill the culvert so it flows full and is dependent on the critical value of the headwater. The critical value for the headwater varies from 1.2 to 1.5 times the height of the culvert depending on the inlet conditions. Critical depth is also a factor in determination of the discharge and is a condition of minimum specific energy. Supercritical flow occurs when the depth of flow is less than the critical depth, while subcritical flow is when the depth of flow is greater than the critical depth.

Type 1 flow exists when both the headwater and tailwater are above the crown of the culvert and a full flow condition exists within the



H = Headwater Depth
y_t = Tailwater Depth
d = Culvert Diameter
L = Culvert Length
y_c = Critical Depth

Figure 9. Types of culvert flow (Chow, 1959)

barrel. Type 2 flow is similar to type 1 flow in that a full flow condition exists in the barrel though the tailwater is below the culvert crown. Flow types 1 and 2 act as pipe flow. Type 3 flow acts as an orifice in that the flow contracts to form a high-velocity jet. For flow types 4, 5, and 6, the culvert functions as a weir since the entrance is not sealed by water. Weir flow differs from orifice flow in that the flow is not contracted to form a high-velocity jet and the losses are typically less. The headwater is less than the critical value. Type 4 flow is subcritical with the outlet unsubmerged, though the tailwater is above the critical depth. Type 5 flow is similar to type 4 flow though the tailwater is below the critical depth. Type 6 flow is supercritical and the tailwater is below critical depth.

Discharges were calculated by using nomographs (Herr and Bossy, 1963). Values of flow were obtained for given headwater and tailwater conditions for three flow regimes. The three regimes were inlet control, outlet control (tailwater level), and outlet control (critical depth). For a given set of conditions the culvert will pass a given discharge for only one headwater condition. Whichever flow regime produced the greatest headwater level for a given flow was selected. This selection was based on the performance of the culvert.

Culvert Capacities

The results of hydraulic computations for the four existing culverts are presented in table 2. The table provides the discharge for given headwater (HW) and tailwater (TW) conditions.

Table 3 includes the 8-foot culvert in addition to the four existing culverts. The capacities both with and without the additional culvert are presented in figure 10. Since no design plans were available, it was assumed that the culvert would be installed with no slope. Headwater values in excess of the road level are not shown. The discharge values represent the flow through all four of the culverts. With no backwater the existing culverts do not quite pass a 2-year flood.

No culvert functioned under inlet control for the headwater and tailwater elevations investigated. All flows were governed by one of the two outlet conditions: tailwater or critical depth. The tailwater had a significant effect in limiting flows through the culvert, especially for

Table 2. Discharge for Various Headwater and Tailwater Conditions (Existing Culverts)

Discharge (cfs)

\ HW TO \ 1	329	330	331	332	333	334	335	336	337
329	0	19	45	70	96	348	568	750	905
330	*	0	45	70	96	348	568	750	905
331	*	*	0	70	96	348	568	750	905
332	*	*	*	0	96	348	568	750	905
333	*	*	*	*	0	348	568	750	905
334	*	*	*	*	*	0	564	750	905
335	*	*	*	*	*	*	0	580	820
336	*	*	*	*	*	*	*	0	580
337	*	*	*	*	*	*	*	*	0

Note: * represents negative flow

Table 3. Discharge for Various Headwater and Tailwater Conditions (With Supplemental Culvert)

Discharge (cfs)

\ HW TW \	329	330	331	332	333	334	335	336	337
329	0	31	63	93	191	551	858	1114	1332
330	*	0	63	93	191	551	858	1114	1332
331	*	*	0	93	191	551	858	1114	1332
332	*	*	*	0	191	551	858	1114	1332
333	*	*	*	*	0	551	858	1114	1332
334	*	*	*	*	*	0	826	1114	1332
335	*	*	*	*	*	*	0	842	1190
336	*	*	*	*	*	*	*	0	842
337	*	*	*	*	*	*	*	*	o

Note: * represents negative flow

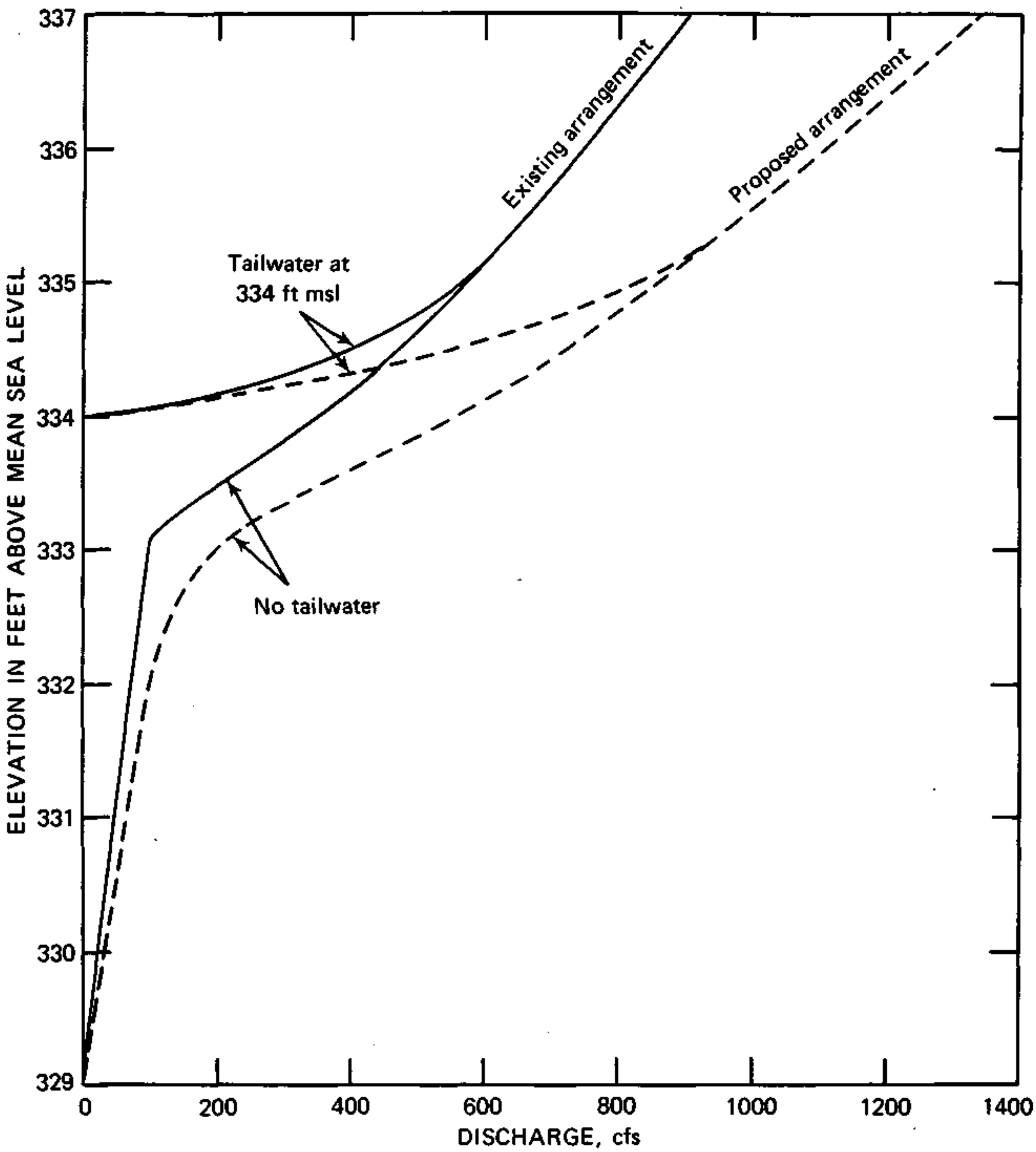


Figure 10. Discharge for the existing and proposed arrangement for two tailwater conditions

headwater elevations below 334 feet msl. At this elevation the water level is 3 feet below Perks Road and 10 percent of the watershed is flooded (figure 4).

During high water stages in the Buttonland Swamp area the backwater could hinder flow though the culverts. Flow would be impeded since the high tailwater elevations at Perks Road reduce the hydraulic head across the culverts, thus reducing flow through the culverts. Therefore, increased culvert capacity at Perks Road may not significantly improve drainage during high water downstream of Perks Road, especially during high backwater conditions downstream of the culverts.

CONCLUSIONS

The results of the hydrologic analysis of the watershed and hydraulic analysis of the culverts indicate that the capacity of the culverts is inadequate to pass a 2-year flood. This is due in part to the culverts being installed with either an adverse or horizontal slope. The flow that does not go through the culverts may overtop the road if the volume and rate of flow are sufficient. An additional culvert would increase the capacity of the existing culverts when the water surface elevation downstream of the culverts is not high. If the water surface elevation downstream of the culverts is high, an additional culvert would not increase the discharge.

With the clearing and draining of additional land, more water would reach the culverts. More efficient drainage in the upper watershed would allow additional water to reach the culverts more quickly, which might further compound the downstream flooding problems.

As was seen during the survey the downstream channel is already at its capacity as evidenced by the drop in elevation of the water surface. A significant portion of the drop in the water surface occurs between the culverts and an area known as the Springs which is located at the edge of Buttonland Swamp. From the Springs to the Cache River there is no longer a well defined channel, and the flow spreads out over a large area. The flow capacity of the channel between the culverts and the Cache River appears to be exceeded. Additional flow would aggravate this situation, which would increase the backwater on the culverts. The next attempt to improve drainage might be to channelize the stream below the culverts. This might allow an efficient conveyance of the floodwaters during low water levels in the Cache River. However, this would also allow additional sediment to be delivered to Buttonland Swamp and negatively impact the wetlands just downstream of the culverts. Most of the sediment is currently being deposited in the channel above and below Perks Road due to the sluggish nature of the flow, caused by lack of a definite channel and by the vegetation downstream of the culverts.

Better drainage would encourage additional development in the watershed. This development would probably come in the form of agriculture. In addition to removing the natural storage capacity in the watershed, which would increase the amount and rate of water coming off the land, the rate of erosion and the amount of sediment would be increased. Some of this sediment would be deposited in the stream channel and would ultimately be deposited in the area adjacent to Buttonland Swamp or the swamp itself. The deposition of sediment in the stream channel would further reduce the flood-carrying capacity of the channel. The addition of an 8-foot-diameter culvert under Perks Road would improve drainage upstream of Perks Road when the water level in the Cache River is low, but should have a negligible impact on drainage when the water level in the Cache-River is high.

SUMMARY

Hydrologic analysis of the watershed and hydraulic analysis of the culverts showed that the existing culverts are inadequate to pass a 2-year flood under any tailwater conditions without overtopping Perks Road. With an additional 8-foot-diameter culvert on a horizontal slope there would be increased capacity under most tailwater conditions. However, the channel below these culverts does not have the capacity to convey the present flow. Increasing the capacity of the channel might be beneficial to help convey the floodwaters during low levels in the Cache River, but would also increase the transport of sediment into Buttonland Swamp. Overall, assuming no direct channel is constructed from the culverts at Perks Road to Buttonland Swamp, there should be little change from the existing conditions by increasing the culvert capacity of Limekiln Slough at Perks Road.

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