The Indiana-Kentucky Boundary Dispute: An Unorthodox Approach to River Hydraulics

ALDO GIORGINI, DEAN RANDALL, ANDREA RINALDO
School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907

Introduction

The two century old boundary dispute between Kentucky and Indiana has been recently settled out of court. Exception made for few locations, the 354-mile border will be at least 100 feet south of the north shore of the Ohio River, and as much as 300 feet at some points. The detailed point by point polygonal will be definitely fixed by experts under the supervision of both parties in the dispute.

The first question that comes to one's mind at this point is whether the boundary between the two states was even fixed in the past and became uncertain (for any number of reasons) with the passing of time, or it was never accurately fixed; thereby creating a *de facto* no-man land between the two states. A sketchy answer to these questions will be outlined in the following paragraphs, with the purpose of giving the background for the complete understanding of the contribution of the computational hydraulic phase to the solution of boundary dispute.

Before the Revolution, Kentucky County was the westernmost settlement of the English Colony of Virginia. What was going to be the Northwest Territory *lying north of the Ohio River*, (comprising what eventually became the States of Ohio, Indiana, Illinois, Michigan, Wisconsin, and Minnesota) was still regarded by the young State of Virginia as its domain. Both the Kentucky County and the Northwest Territory were protected against terrorist action of British soldiers, pro-British American Loyalists (Tories) and allied Indians by guerrilla counteraction as the one led by the young Virginia surveyor George Rogers Clark, under commission of Virginia Governor Patrick Henry (7).

At the end of the George Rogers Clark's feats, in 1779, the Virginia Legislature elevated the Virginia County of Kentucky to the status of the Province of Kentucky and it declared the *country north of the Ohio River* to be the new Virginia County of Illinois. Elections were held the same year and Virginia could claim to be functioning as the State government throughout the territory north of the Ohio River all the way to the Canadian border.

The continuous efforts to defend the lands of the Midwest had improverished Virginia to the point that it was alleged that the State was planning to sell directly to individual settlers all of its claims north of the Ohio River. On September 6, 1780 Congress passed a resolution calling on all the States for "a liberal surrender of portion of their territorial claims, since they cannot be preserved entire without endangering the stability of the general confederacy . . ." and, on October 10, demanded that those lands "be settled and formed into distinct republican states, which shall become members of the federal union and have the same rights of sovereignity, freedom and independence, as the other states."

On March 1, 1784, with the first land cession, Virginia released "all right, title and claim . . . to the territory *northwest of the river Ohio*."

On June 1st, 1792, when the State of Kentucky was created, its northern boundary was declared to be "the north bank of the river Ohio at low water mark".

When Indiana was admitted into the Union as its 19th member, on December

11, 1816, the boundary between Indiana and Kentucky was therefore the north bank of the Ohio River as it was, at low waters, in 1792.

While during the nineteenth century no serious disputes arose about the boundary between Kentucky and the trans-ohian states of Illinois, Indiana and Ohio, the nineteenth century has seen several disputes brought to the United States Supreme Court, which consistently dodged the boundary question. A brief listing of the Court's actions follows:

1966—The State of Ohio files an original action in the United States Supreme Court, asserting that the boundary between Ohio and Kentucky is the 1792 low-water mark.

1971—The State of Ohio tries to amend its 1966 Complaint in the Supreme Court, arguing that the boundary should be the middle of the river.

1973—The Supreme court dismisses the case sustaining that Ohio should have raised its "middle of the river" argument when it became a state in 1803.

1980—The Supreme Court, by a vote of 6 to 3, upholds Ohio's position that *the boundary was forever fixed at the 1792 low-water mark*, against the Kentucky contention that the boundary between the three states and Kentucky was not fixed forever at the 1792 low-water mark. Soon after the *Ohio v. Kentucky* decision was made, Indiana's Attorney General, Theodore L. Sendak, asked the Supreme Court to make the same ruling in *Kentucky v. Indiana*, which the Supreme Court granted on March 24, 1980.

This date is the end of the dispute about the *definition* of the boundary between Indiana and Kentucky: *the boundary is the 1792 low-water mark.*

What was left was its *determination*. This task was not a straight-forward one, since rivers do change their course in time, and since there are neither accurate 1792 maps of the Ohio river nor hydrologic data that give the value of the 1792 low-water surface elevation. The task could actually be one of gigantic proportions, with involvements of land surveyors, geologists, hydrologists, river hydraulics experts, etc . . . if it were necessary to litigate one by one the 354 miles of the boundary. This was, in fact, not done. Only key locations were subjected to extensive research. One of these locations, which is the object of this report, extends from McAlpine Dam in Louisville, located where once were the Chutes, and Six-mile Island, near Utica, six miles upstream of the Chutes, where the third State-owned port in Indiana, the Clark Maritime Center, is planned to be built.

This paper presents the comutational hydraulic phase of the research project on the Chutes-Six-mile Island reach of the Ohio River.

Formulation of the Problem

The problem can be formulated in rather simple terms: *given the bathymetry of the Ohio River reach that starts at the Louisville Chutes and ends at Six-mile Island, and given the low-water elevations of the reach, find the north shore.*

As such the problem is a characteristically geometrical problem whose solution is exclusively within the province of the land surveying discipline. What makes the problem a wider scope problem involving other disciplines is the fact that what should be given is actually not known, and has to be found or estimated by those other disciplines.

The data of the problem are: the bathymetry of the reach under study as it was at the time of low waters in 1792, and the low-water elevations of the same reach, at the same time. The finding of these data is the object of other discipline's problems.

As for the 1792 bathymetry, since no records prior to those collected during the survey of 1911-1914 have the accuracy required for the determination of the boundary, the problem can be cast in the following terms: is it possible to infer the 1792 bathymetry from the maps printed by the Army Corps of Engineering, following the 1911-14 survey of the Ohio river? This can obviously be done if the river has not changed in the time span 1792-1911 or if its movements can be traced accurately. Geological evidence (10) points at the very stable nature of the northern shore of the Ohio river, especially around Six-mile Island where "the sum of the geological evidence suggests that the Ohio river has not been displaced north or west of the present position in historic time, nor probably even earlier". Graphical comparison of the cross-sections of the river as obtained from the 1911-14 survey and from the 1964 survey has confirmed the geological findings by showing that only minor changes have occurred in the Ohio River reach under consideration in the past 50 years, and that these, due mainly to the effect of the building of McAlpine Dam, are not affecting the northern shore near Six-mile Island (2).

The problem of the 1792 low-water mark is actually much more complex. In lack of any numerical data of that time, and since low-water marks do change from year to year, one must obviously relinquish the thought of finding the true low water elevation in 1792 and accept the concept of "probable" low water elevation in 1792. It is here that history, hydrology, and computational hydraulics fuse together to yield alternate answers with different probability attributes. Historical accounts point at the fact that several times the Ohio Chutes of Louisville had so little water that herds of buffalo were crossing the river (8). Furthermore some correspondence between Major General Henry Knox, Secretary of War, and Major General Anthony Wayne (9) which was kindly brought to the authors' attention by William Krisle, suggests that during the summer of 1792 the Ohio River was flowing as a mere trickle down the Chutes, and was probably dry in several reaches. This account of the discharge conditions points at an elevation of the water surface in the pool stretching from the Chutes to Six-mile Island of roughly 400.7 feet above the mean sea level. The effects of this pool level on Six-mile Island are shown in Figure 1-a (3).

As for the hydrological counterpart of the historically based 400.7 foot pool elevation, it has been found that the lowest recorded stage since the year 1858 occurred in the years 1881 and 1895 and was 404.7 feet (10). The average return period of such stage or lower has been shown to be 20-30 years. Albeit the probability of the low-water stage in the pool under consideration being equal to or lower than 404.7 in any given year is only 3-5%, the historical findings mentioned above indicate that the low-water mark of 1792 might have been a still rarer occurrence.

Furthermore the 404.7 stage was measured when the river had manmade structures that were increasing the pool level. The effects of a 404.7 pool level on Six-mile Island are shown in Figure 1-c.

The Hydraulic Problem

The computational hydraulics phase of the search for the 1792 low-water mark has its inception with the realization that the low water mark of 404.7 feet, obtained from a survey conducted that year, and reported on a 1903 map, has acquired the status of *standard* low water mark for the maps that were issued after the 1911-14

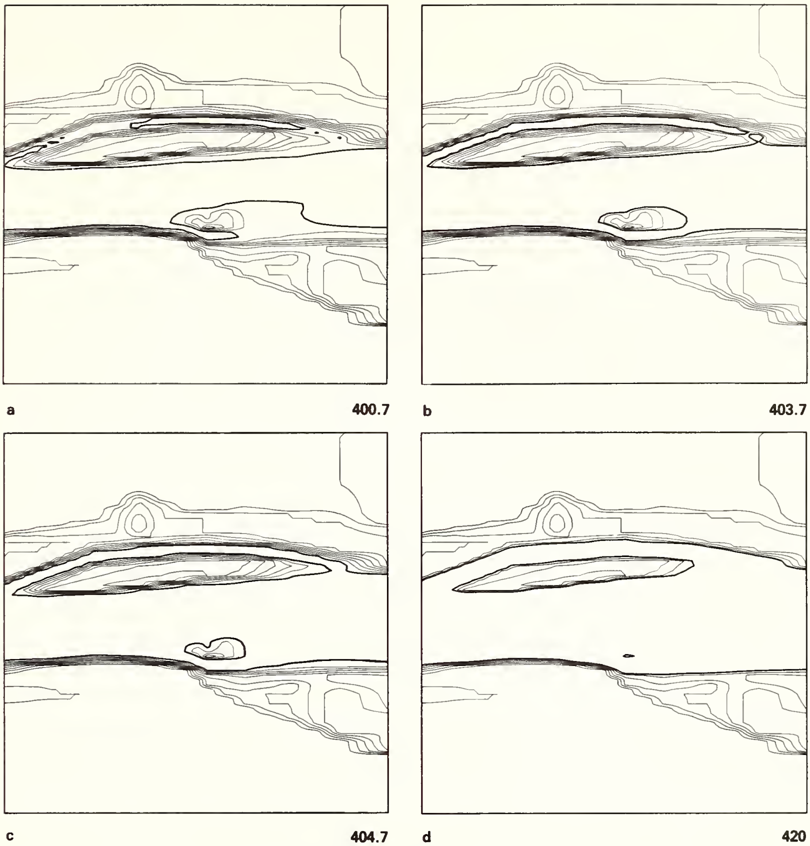

FIGURE 1. *Shoreline configuration near Sixmile Island: a. at stage 400.7 ft, when the Louisville Chutes were dry; b. at stage 403.7 ft, this paper's upper estimate for the 1792 low water mark; c. at stage 404.7 ft, low water mark of 1895 when a wing dam was present; d. at stage 420, ft, nowadays normal pool level, after the construction of McAlpine Dam.*

survey and after the 1964 survey. The realization that such low water mark was measured when a wing-dam was lying across the Middle Chute, with the purpose of conveying the discharge of the river through the Indian Chute (see Figures 2 and 3) in order to facilitate navigation, suggested that the 409.7 foot low-water mark was corresponding to a discharge which would have yielded a still lower low-water mark, had the wing-dam not been there, that is, had the Chutes condition been natural, as they were in 1792. The hydraulic problem was therefore clearly formulated: given the pool elevation of 404.7 feet and the wing-dam on the Chutes, find the corresponding discharge to the discharge just found, which should be lower than 404.7 feet.

The first phase of the problem solution was the study of geometric characteristics of the river bed. The entire reach from the Chutes to Itaca, as recorded in 1911-14 survey and the 1964 survey, was digitized section by section (1),

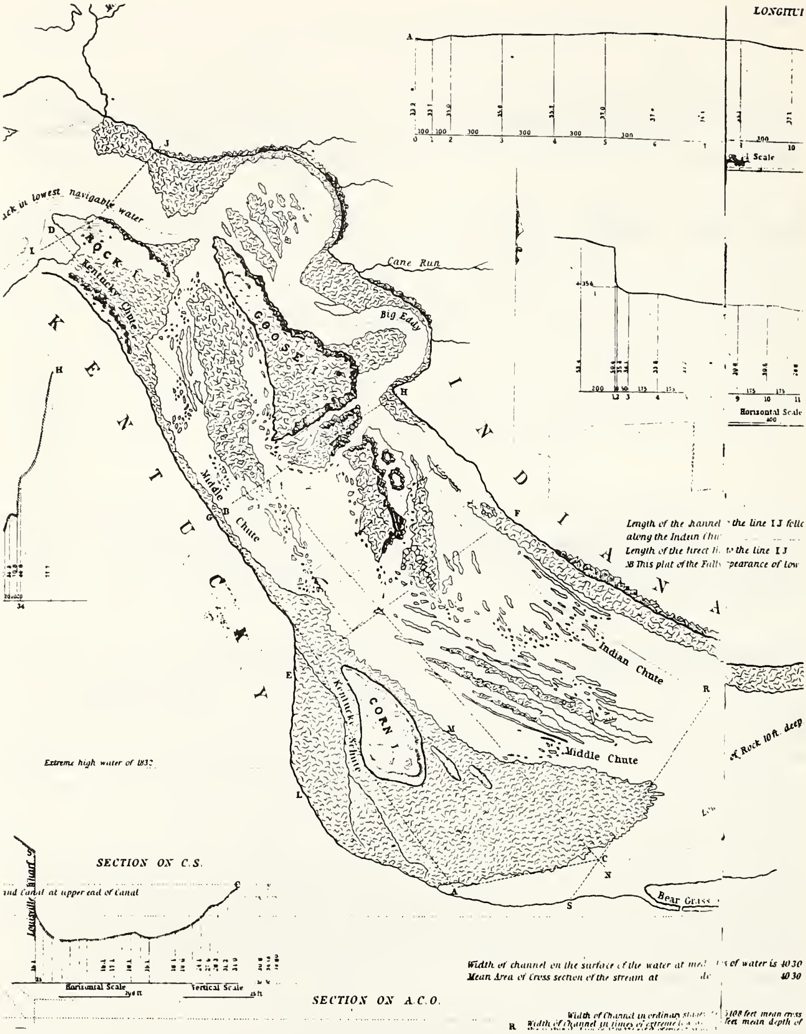

FIGURE 2. *Map of the Ohio Chutes as drawn in 1843 by Capt. Cram, presenting the 1809 low water conditions.*

the data of the two surveys were compared (2), and the two numerical models so obtained were formatted for use in the HEC2 program (6), a FORTRAN program developed by the Army Corps of Engineers for the calculation of water surface profiles in rivers. The numerical model resulting from the data of the 1964 survey were used to check whether the HEC2 program was yielding results comparable to measured elevations at different discharges (3). Upon satisfactory conclusion of the comparison, and upon definite verification of the fact that, from a hydraulic viewpoint, the reach under consideration (see Figure 5) behaves like a pool for low and intermediate discharges, the direction of the research was clearly dictated: the

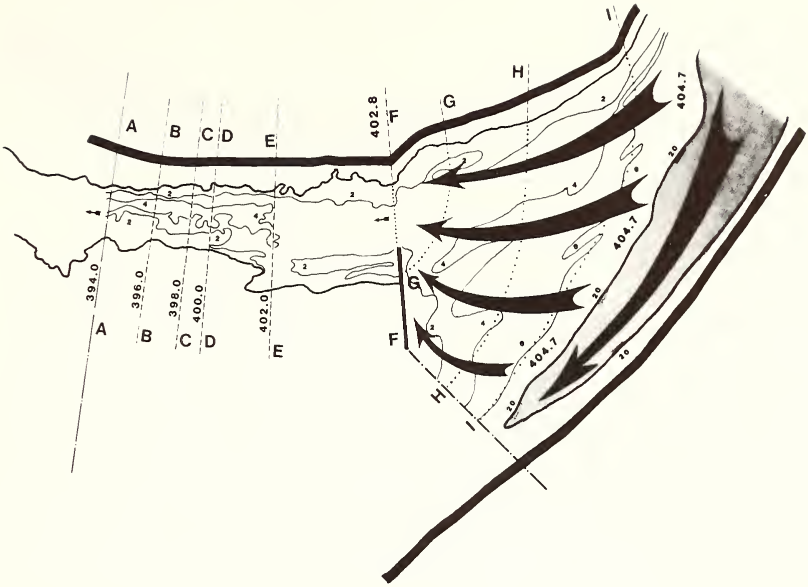

FIGURE 3. *Sketch of the 1903 map with wing dam.*

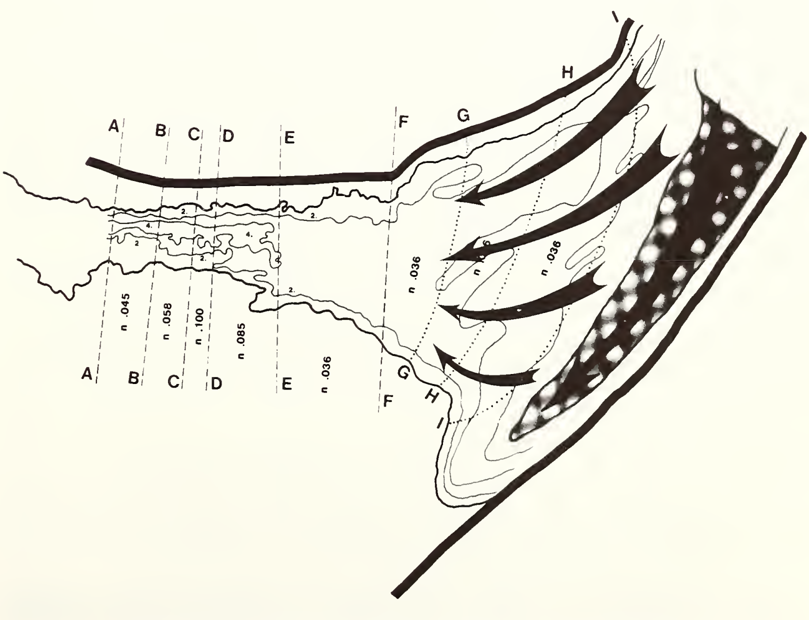

FIGURE 4. *Sketch of the 1903 map without wing dam.*

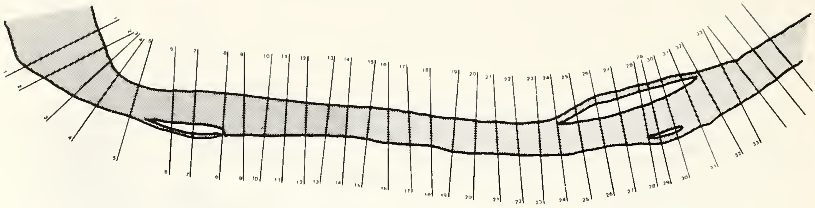

FIGURE 5. *Sketch of the Ohio River reach that ranges from the Ohio Chutes (roughly around cross section 1) and Sixmile Island (encompassing section 24 and section 32). The cross sections numbered in the sketch are those surveyed in 1911-14.*

numerical modeling of the Chutes. This phase could have been reduced to something slightly better than guesswork, were it not for the unexpected intervention of the 1903 map, which yielded contour lines of the whole Chutes region and surface water elevations at some cross sections. A schematic representation of this map, showing the wing-dam, is presented in Figure 3. This figure clearly shows that the Ohio River bed presents a diffuser-like behavior near the Chutes: the stream approaches the Chutes in a deep trench and overflows from it, almost orthogonally, to converge almost radially toward section FF. The computer simulation was therefore formulated by defining curved cross sections like II, HH, and GG, gradually closing onto section FF. After that section, the traditional rectilinear definition of cross section was kept intact. It was assumed that, at low discharges, the water velocity at the deep trench is negligible (since its depth exceeds 20 feet). The whole geometrical properties of the problem were therefore clearly defined. What was not known was the friction characteristic of each trunk from section to section, expressed in terms of the Manning's coefficient n.

It was therefore decided to infer the Manning's n of each trunk by using the measured elevations at each end. The process is a rather laborious one. It starts with the finding of all the flowrates Q_A, Q_B, . . . Q_F that would make the sections AA, BB, . . . , FF respectively critical. The lowest of these flowrates, if ever reached in the instance at hand, would be the controlling flowrate of the discharge. It was found that the first section to become critical is section FF, with a discharge of 7550 cfs. All other cross sections have tranquil regime for this flowrate.

For each trunk of the model, given a value of Manning's n, is always possible to find a flowrate Q that yields the given water elevations at the trunk ends. The locus Q vs. n, for each one of the trunks, has been plotted in Figure 6. In the figure we can see that, for the "critical" flowrate 7550 cfs, the Manning's n coefficients are at their lowest values, albeit the value of n for the trunk CD is more than three times the value of n for trunk FI.

Since we do not know with certainty the value of n for any one trunk of the reach under study, we should resort to educated guesses. These are:

a) Since the Army Corps of Engineers gives a global coefficient n = .03 for the region upstream of FF, we could assume that this is the value of n for the trunk FI. If that be the case, the discharge on the Chutes would be 6000 cfs;

b) Assuming that the trunk EF and FI have the same value of n, since they appear homogeneous in the map, we can obtain n = .035, with a flowrate of 5400 cfs;

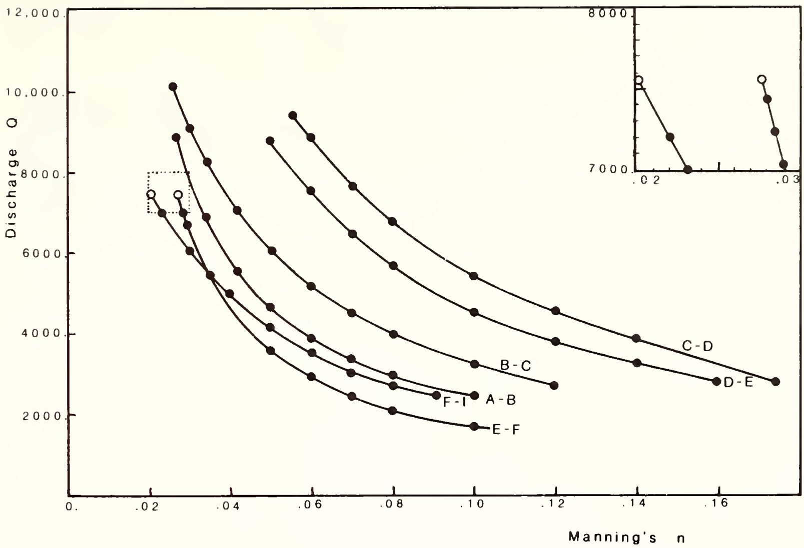

FIGURE 6. *The Ohio Chutes trunk's loci of the couples (Q,n) which yield the measured stages at both ends of each trunk.*

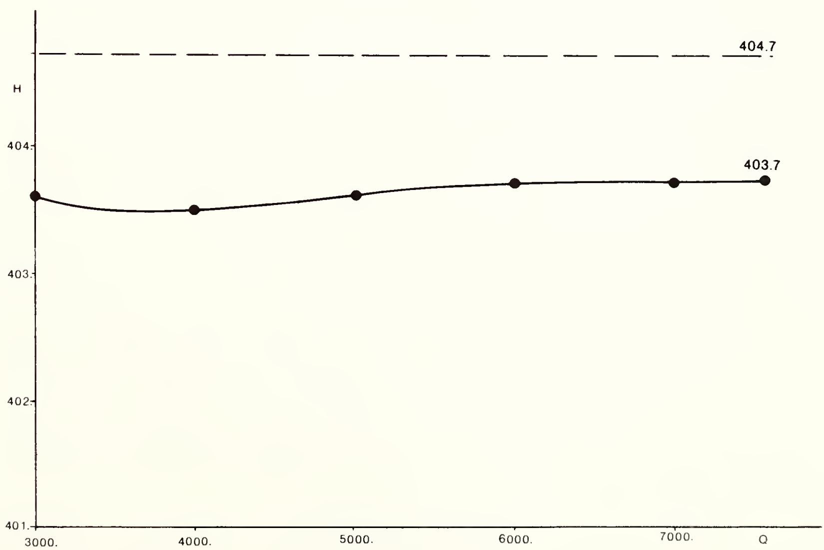

FIGURE 7. *Pool elevations corresponding to different discharges (and different roughnesses).*

c) We could argue that critical depth is actually reached in section FF, thereby concluding that the discharge is 7550 cfs.

We should recall that any one of the above alternatives yields exactly the whole free surface profile along the Chutes, as given by the 1895 measurements. The choice between any one of the above alternatives may depend on factors that depend on personal experience. It has been decided therefore to try all possible models, with different values of n, for flowrates corresponding to the range 3000 to 7550 cfs. The lower limit of 3000 cfs has been chosen because under that value the Manning's n for trunks CD and DE become unphysical.

For each set of n shown in the following table-like scheme

	AB	BC	CD	DE	EF	FI
Q = 3000	n = .078	n = .108	n = .170	n = .150	n = .046	n = .071
Q = 4000	n = .057	n = .079	n = .135	n = 115	n = .045	n = .055
Q = 5000	n = .046	n = .062	n = .106	n = .090	n = .037	n = .040
Q = 6000	n = .038	n = .050	n = .090	n = .075	n = .032	n = .030
Q = 7000	n = .033	n = .041	n = .076	n = .064	n = .029	n = .023
Q = 7550	n = .031	n = .039	n = .071	n = .059	n = .0278	n = .021

and for the corresponding flowrate a numerical simulation has been performed with the wall removed, as shown in Figure 4, and the elevation of the pool so obtained has been plotted in Figure 1.

The result shows clearly that the alternatives suggested at the beginning of this section, no matter how different they seem, yield almost the same result: the pool level after the wall has been removed is at least one foot below the 404.7 low water mark. The free surface profiles for the case Q = 7550 cfs with wing-dam and without it, are presented in Figure 8 and Figure 9 respectively.

Conclusion

Since the 1792 low water mark cannot be determined with certainty, the 1895 low water mark can be taken as a "conservative" substitute for it. It has been shown that the 404.7 ft 1895 low water mark was affected by a wing-dam whose removal, to restore the 1792 virgin conditions, lowers the water level to 403.7 (as shown in Figure 1-b for its effects on Six-mile Island). Since all the estimates are conservatives there is a definite probability that, at low waters, Six-mile Island was an Indiana peninsula. Comparison should be made between Figure 1-b, presenting the conservative estimate derived in this paper, and Figure 1-d, presenting the nowadays normal pool conditions with a stage of 420 ft. That comparison shows that, if the 403.7 stage is accepted as the boundary definition, Indiana's boundary with Kentucky is within the waters of the Ohio River. The argument is strong and, as it happened, persuasive. Whether the actual boundary, as sketched in the introduction, and the 403.7 stage boundary are coincident, is matter of no consequence, since the last has helped the formulation of the first.

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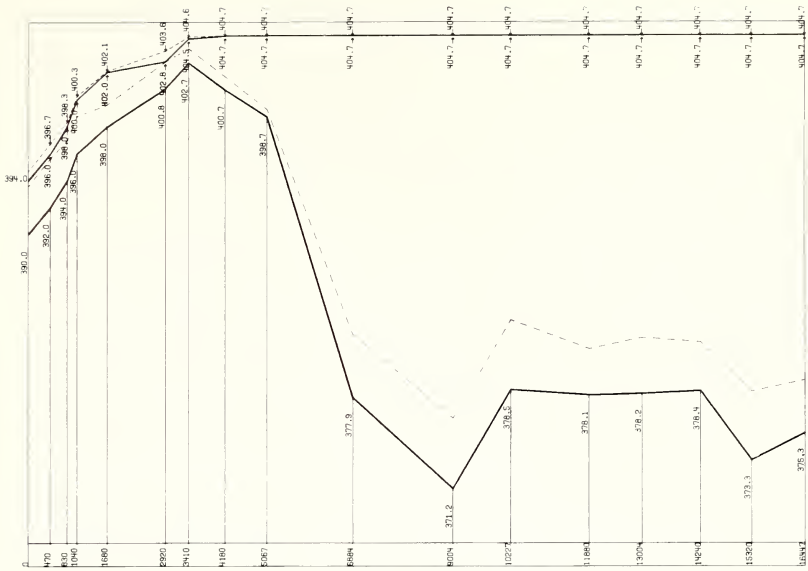

FIGURE 8. *Water profile along the Chutes for a discharge of 7550. cfs when the wing dam is present.*

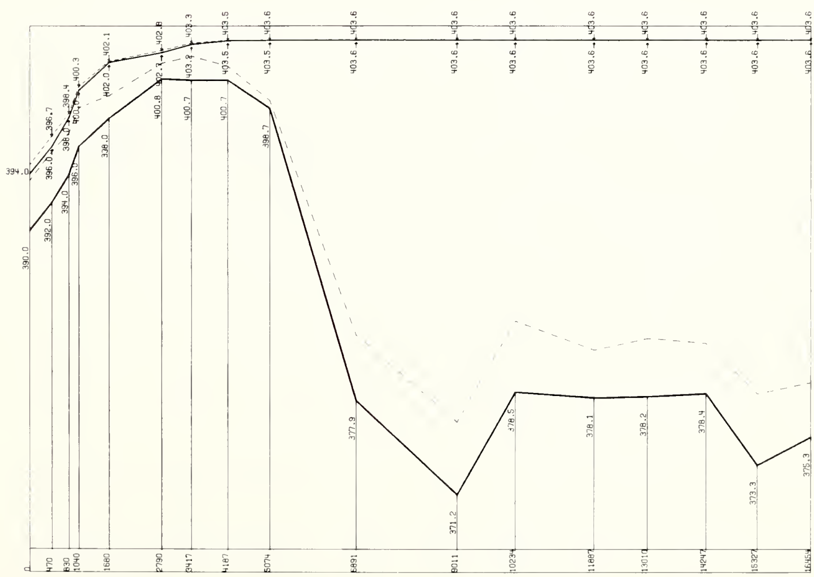

FIGURE 9. *Water profile along the Chutes for a discharge of 7550. cfs without the wing dam.*

General Linley E. Pearson, Special Counsel William E. Daily and Assistant Counsel Thad Perry for the opportunity to work on such an interesting project.

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