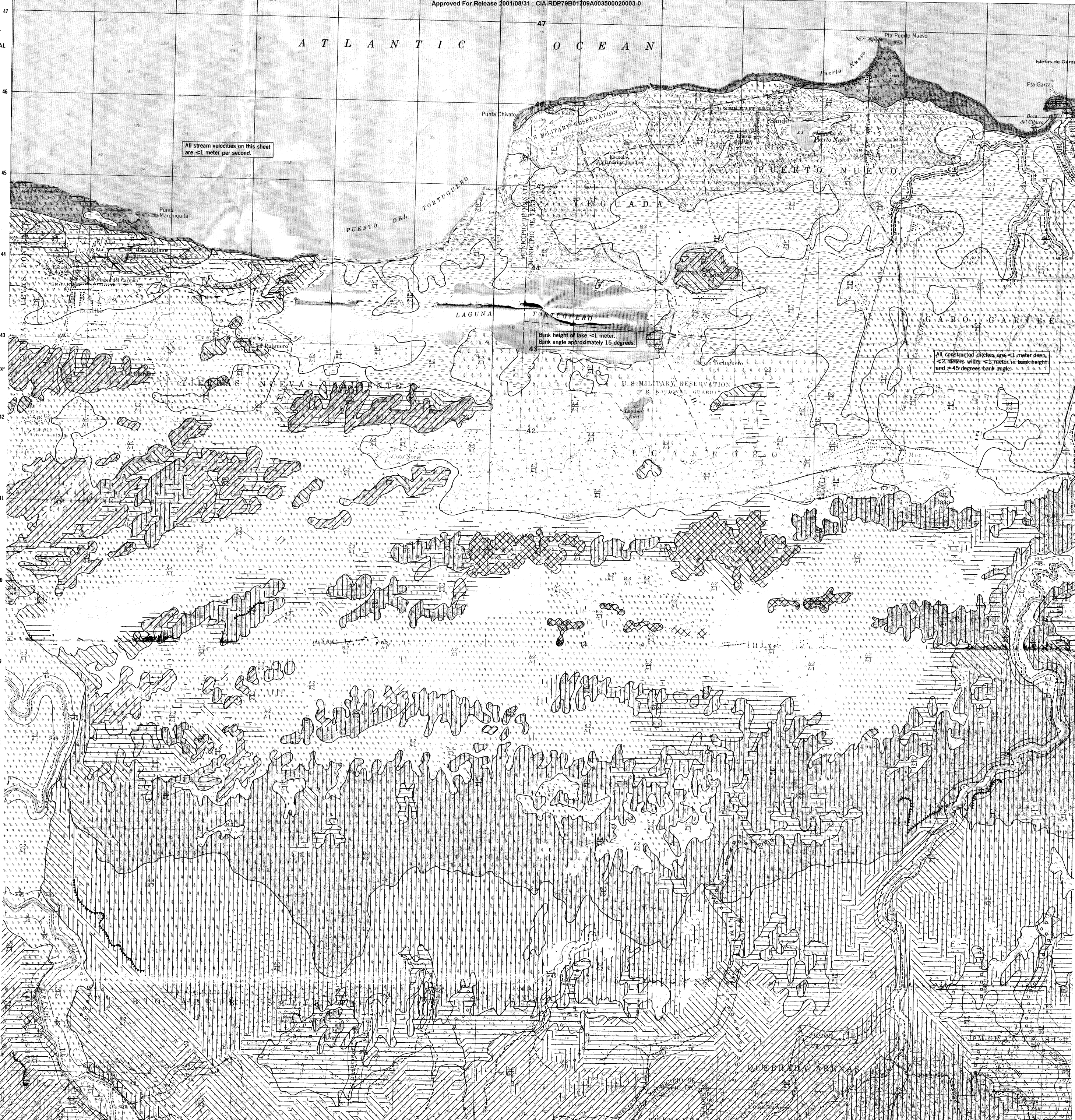
EXPERIMENTAL

GROUND TACTICAL DATA

MANATI



Base map edited, and published by the Geological Survey. Control by USGS and USC&GS. Terrain data overprint prepared by USAETL and EARI.

PERCENT OF SLOPE

	0–3%		25–45%
	3–10%		45–100%
	10–25%		>100%

SOILS

MAP UNIT	DOMINANT SOIL TYPE*	SOIL GROUP**	DEPTH (METERS)	MAP UNIT	DOMINANT SOIL TYPE*	SOIL GROUP**	DEPTH (METERS)
	Tanamá stony clay	GC, CL	<0.5		Toa fine sandy loam to silt loam	CL	>5.0
	Cataño sand	SP, SM	>5.0		Colinas stony clay loam	CL, GC	1.0–3.0
	Guayabo fine sand	SM	3.0–5.0		Coloso silty clay loam to clay	CH, CL	>5.0
	Bayamón fine sandy loam	ML, CL	2.0–5.0		Tiburones muck	OH, OL, CH	>5.0

*Locally named agricultural soil **Unified Soil Classification System (USCS)

SCALE 1:20,000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 5 0 1 KILOMETER

CONTOUR INTERVAL 5 METERS
DOTTED LINES REPRESENT 1-METER CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 0.3 METERS

SURFACE DRAINAGE

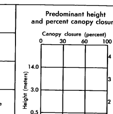
STREAM DEPTH	STREAM WIDTH			
	>100 Meters	40–100 Meters	20–40 Meters	<10 Meters
Perennially ≥1.5 meters				
Perennially <1.5 meters				
Intermittent <1.5 meters				

$\frac{<1}{>45}$ Bank height in meters. Bank angle in percent

VEGETATION

	Grassland (pasture)
	Brush
	Forests
	Cultivated Crops (predominantly sugar cane and pineapple)
	Mixture of cultivated crops, woodland and grass
	Orchards
	Marshes & Swamps

Predominant height and percent canopy closure



EXAMPLE:

B-3 — 30 to 60% canopy closure; 3.0 to 14.0 meters in height — Veg. Story

A-1 — 0.0 to 0.5 meters in height; 0 to 30% canopy closure — Ground Cover

TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: 1927 NORTH AMERICAN DATUM

BLACK NUMBERED LINES INDICATE THE 1,000 METER UNIVERSAL TRANSVERSE MERCATOR GRID, ZONE 19, CLARKE 1866 SPHEROID

USERS ARE URGED TO REFER CORRECTIONS AND COMMENTS FOR INCREASING THE USEFULNESS OF THIS MAP TO COMMANDING GENERAL, U. S. ARMY TOPOGRAPHIC COMMAND, WASHINGTON, D. C. 20315

GRID ZONE DESIGNATION: 19Q	TO GIVE A STANDARD REFERENCE ON THIS SHEET TO NEAREST 100 METERS	
100,000 M. SQUARE IDENTIFICATION: GL	SAMPLE POINT: CANTERA	
	1. Read letters identifying 100,000 meter square in which the point lies:	GL
	2. Locate first VERTICAL grid line to LEFT of point and read LARGE figures labeling the line either in the top or bottom margin, or on the line itself: Estimate tenths from grid line to point:	69 3
IGNORE the SMALLER figures of any grid number; these are for finding the full coordinates. Use ONLY the LARGER figures of the grid number; example: 2034000	3. Locate first HORIZONTAL grid line BELOW point and read LARGE figures labeling the line either in the left or right margin, or on the line itself: Estimate tenths from grid line to point:	40 4
	SAMPLE REFERENCE:	GL693404
	If reporting beyond 9°N-S or 18°E-W, prefix Grid Zone Designation, as:	19QGL693404

EMBANKMENTS AND ESCARPMENTS

Face height ≥2 meters; Face slope ≥100%

11-69 PRINTED BY THE U. S. ARMY TOPOGRAPHIC COMMAND

7°

TRUE NORTH

MAGNETIC NORTH

APPROXIMATE MEAN DECLINATION, 1958

PUERTO RICO

QUADRANGLE LOCATION

CAUTION: Some data on this sheet have been fictionalized to illustrate design principles.

Approved For Release 2001/08/31 : CIA-RDP79B01709A003500020003-0

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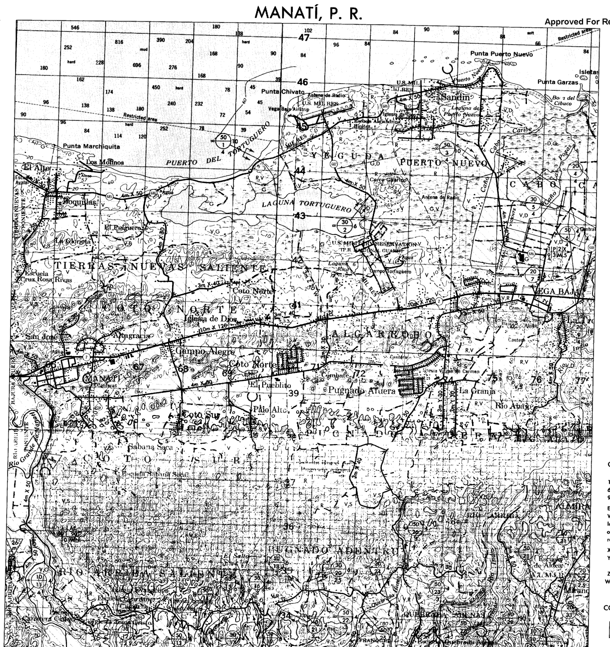
VEHICLE MOVEMENT



BRIDGE

A. Class
B. Bridge number
C. Vertical clearance
D. Roadway width/horizontal clearance
E. Length
F. Bypass condition

Easy
Difficult
Impossible

NOTE:
N/I No information

FERRY

A. Ferry number
B. Ferry type
1. AF—Vehicular
2. PF—Foot
3. MF—Military
C. Military load classification
D. Dead weight capacity
E. Turn around time
F. Cargo space width
G. Cargo space length
H. Arrow extends to ferry location
I. Approach conditions, left shore
1. Easy
2. Difficult
J. Approach conditions, right shore
1. Easy
2. Difficult

Ford

A. Ford number
B. Ford type
1. A—Vehicular
2. P—Foot
3. D—Deepwater, tank
4. S—Swimming vehicles
C. Stream velocity (Meters per second)
D. Seasonal limitations
1. X—none
2. Y—significant
E. Length (Meters)
F. Width (Meters)
G. Bottom type
1. M—Mud
2. C—Clay
3. S—Sand
4. G—Gravel
5. R—Rock
6. P—Artificial
H. Depth (Meters)
I. Arrow points to ford location
J. Approach conditions, left bank
1. Easy
2. Difficult
K. Approach conditions, right bank
1. Easy
2. Difficult

ROADS

ROUTE CLASSIFICATION FORMULA

10.5m X 120
6m Z 8 (OB)
9m Y 20 (OB) W

Expressed in order of: Width, type, military load classification, obstructions, and regular flooding:

X—All weather route
Y—All weather route (Limited traffic)
Z—Fair weather route
W—Regular flooding

WIDTH CONSTRICTION

1m

Route constriction in width; Width in meters of usable travelway in triangle corresponding to the side of the travelway in which the constriction occurs.

NOTE: On this map a lane is considered as being a minimum of 2.4m (8 feet) in width.

Scale 1:50,000

1 ½ 0 1 2 3 Statute Miles
1000 500 0 1000 2000 3000 4000 Meters
1000 500 0 1000 2000 3000 4000 Yards
1 ½ 0 1 2 3 Nautical Miles

CROSS COUNTRY SPEED FOR M151

MAP UNIT	SPEED RANGES (Miles per hour) M151
	> 20
	10-20
	5-10
	0-5
	0

TERRAIN FACTORS WHICH LIMIT VEHICLE SPEEDS

D—Drainage
G—Surface strength
R—Surface roughness
S—Slopes
V—Vegetation

POTENTIAL AMBUSH SITE

GRADES

5–7%
7–10%
10–14%
OVER 14%

Arrows point in uphill direction. Length of arrow represents length of grade.

Hard surface, two or more lanes
Loose surface, two or more lanes
Hard surface, one lane
Loose surface, one lane

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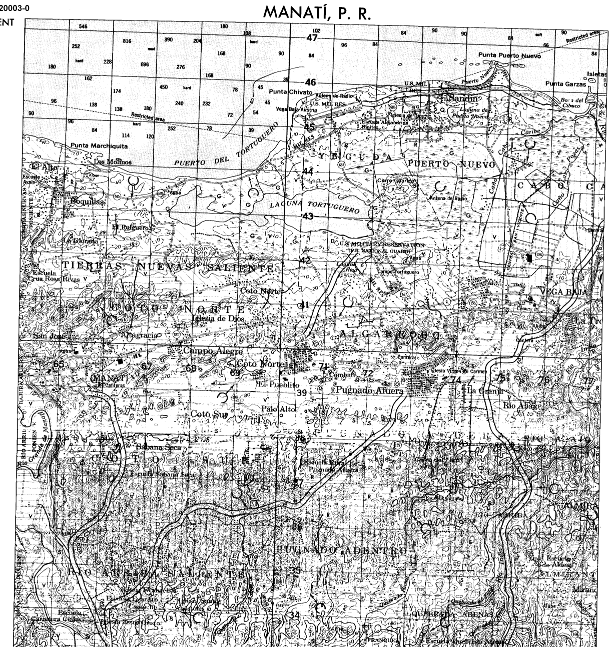
FOOT MOVEMENT



Scale 1:50,000

1 ½ 0 1 2 3 Statute Miles
1000 500 0 1000 2000 3000 4000 Meters
1000 500 0 1000 2000 3000 4000 Yards
1 ½ 0 1 2 3 Nautical Miles

CROSS COUNTRY MOVEMENT SPEEDS FOR FOOT TROOPS

MAP UNIT	SPEED RANGES (Miles per hour)
	3–4
	2–3
	1–2
	< 1

TERRAIN FACTORS WHICH LIMIT SPEED OF MOVEMENT

D—Drainage
G—Surface strength
R—Surface roughness
S—Slopes
V—Vegetation

Trails greater than 1 meter wide
Trails 1 meter or less in width
Potential ambush site
Potential infiltration route

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FOXHOLE CONSTRUCTION and EXISTING COVER

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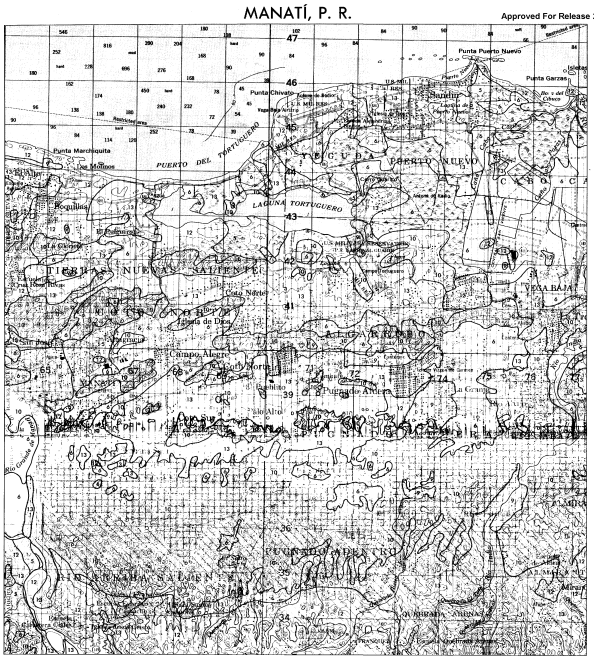

Scale 1:50,000

1 ½ 0 1 2 3 Statute Miles
1000 500 0 1000 2000 3000 4000 Meters
1000 500 0 1000 2000 3000 4000 Yards
1 ½ 0 1 2 3 Nautical Miles

TIME REQUIRED TO CONSTRUCT TWO MAN FOXHOLE

1.2 METERS (2 FT) DEEP

MAP UNIT	CONSTRUCTION TIME REQUIRED IN HOURS. TWO MEN WORKING
	0–1 hours
	1–2 hours
	> 2 hours
	Unsuited because of high water table
	Unsuited because of rock or extremely hard surface

Not all Map Units occur on this sheet.

MAP UNIT	COVER CODE A	B	C	D
1	1	2	1	1
2	1	1	1	2
3	1	3	1	1
4	1	3	1	2
5	2	1	1	1
6	2	1	1	2
7	2	1	2	1
8	2	1	2	2
9	2	2	1	1
10	2	2	1	2
11	2	2	2	2
12	2	3	1	1
13	2	3	1	2
14	2	3	2	2

COVER CODES AND CLASS RANGES

A. Probability of incoming projectiles (artillery, mortar, and bombs) reaching an effective height (2 meters) above ground before detonation.

Class	Class Range (percent probability)
1	0–60
2	60–100

B. Horizontal distance at which all small arms fire is blocked.

Class	Class Range (meters)
1	0–20
2	20–40
3	40

C. Largest size of objects covered from flat trajectory fire.

Class	Class Range (centimeters)
1	15 x 30 x 200 (man)
2	75 x 150 x 300 (jeep)

D. Number of jeeps that can be covered by the overhead cover per 1000 m^2

Class	Class Range (number of vehicles)
1	0–12
2	12–35

EXAMPLE: Map unit 7 = Cover code 2121
2. 60–100% probability of projectiles reaching 2 meters height before detonation.
1. Small arms fire blocked between 0–20 meters.
2. Jeeps are covered at distances between 0–20 meters from flat trajectory fire.
1. 0–12 jeeps may be placed under overhead cover within an area of 1000 m^2

CAUTION: Some data on this sheet have been fictionalized to illustrate design principles.

CONCEALMENT

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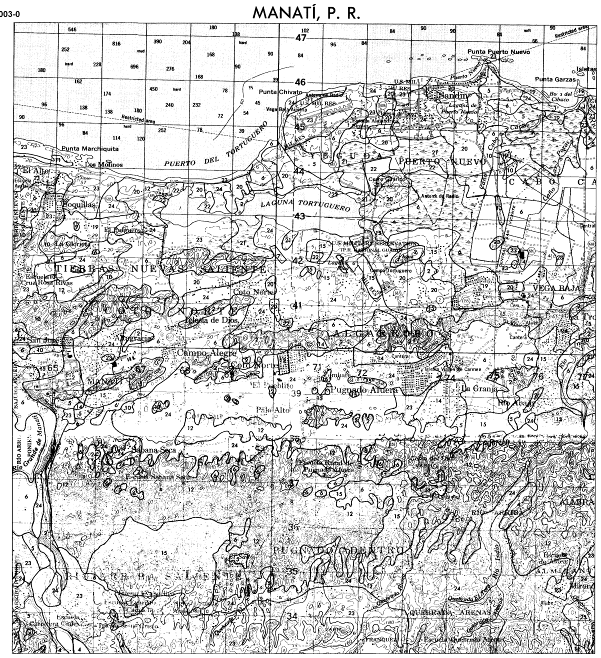


Scale 1:50,000

1 ½ 0 1 2 3 Statute Miles
1000 500 0 1000 2000 3000 4000 Meters
1000 500 0 1000 2000 3000 4000 Yards
1 ½ 0 1 2 3 Nautical Miles

Not all Map Units occur on this sheet.

MAP UNIT	CONCEALMENT CODE A	B	C	D
1	1	3	1	1
2	1	3	1	2
3	1	4	1	1
4	1	4	1	2
5	2	1	1	1
6	2	1	1	2
7	2	1	2	1
8	2	1	2	2
9	2	2	1	1
10	2	2	1	2
11	2	3	1	1
12	2	3	1	2
13	2	5	1	2
14	3	3	1	1
15	3	3	1	2
16	3	3	2	2
17	3	4	1	1
18	3	4	1	2
19	3	5	1	1
20	3	5	1	2
21	4	2	1	1
22	4	2	1	2
23	4	5	1	1
24	4	5	1	2

CONCEALMENT CLASSES AND CLASS RANGES

A. Probability of being observed from the air.

Class	Class Range (percent)
1	5
2	5–10
3	10–35
4	35–100

B. Distance at which horizontal line of sight 2 meters above surface is completely obsured.

Class	Class Range (meters)
1	0–5
2	5–20
3	20–50
4	50–250
5	>250

C. Largest size of objects which can be concealed from observation by ground observer.

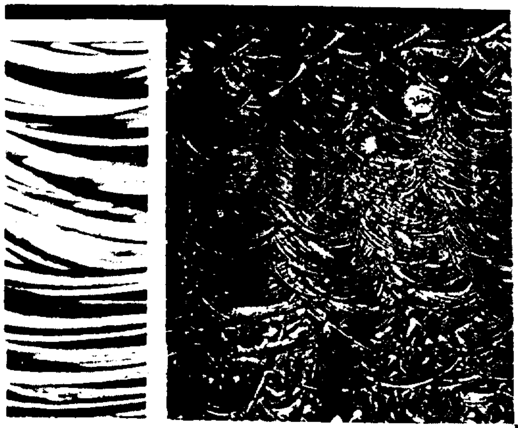
Class	Class Range (centimeters)
1	15 x 30 x 200 (man)
2	75 x 150 x 300 (jeep)

D. Number of jeeps which can be concealed from air observation within a 1000 m^2 area.

Class	Class Range (number)
1	0–12
2	12–35

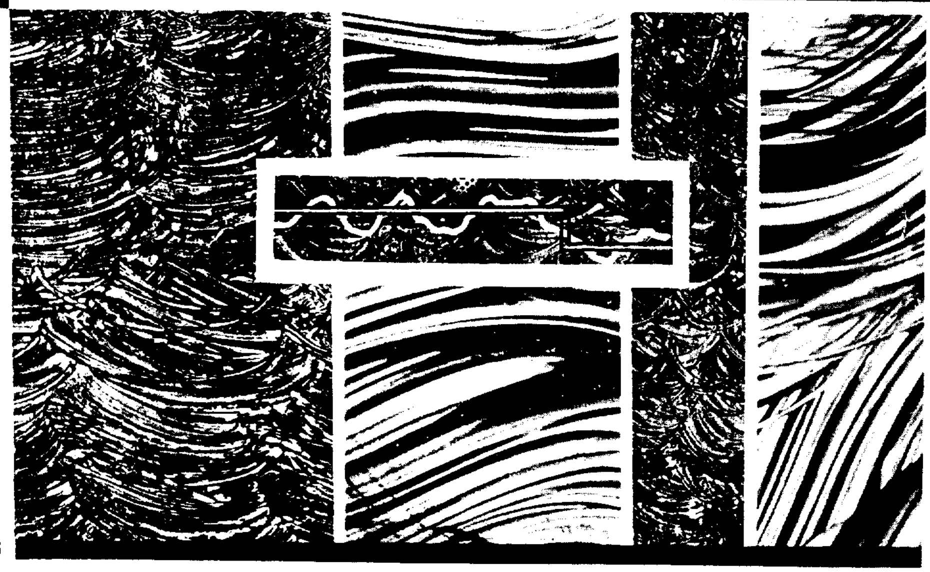
EXAMPLE: Map Unit 15 = Concealment Code 3312
3. Probability of being observed from the air is 10–35%.
3. Horizontal line of sight is blocked between 20 and 50 meters from point of observation.
1. A man is the largest object that is concealed at a distance of 20–50 meters from the point of observation.
2. From 12 to 35 jeeps can be concealed from aerial observation in an area 1000 m^2

CAUTION: Some data on this sheet have been fictionalized to illustrate design principles.



Lake Michigan – Wabash River

Barge Canal



Volume I of II

A Preliminary Engineering Study

October 1969

Prepared by

Engineer Strategic Studies Group
Office, Chief of Engineers
Department of the Army

WARNING

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Same photos under
Sopa in M. Mclain's office

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LAKE MICHIGAN - WABASH RIVER BARGE CANAL

(A Preliminary Engineering Study)

Volume I of II

Prepared by

Engineer Strategic Studies Group
Office, Chief of Engineers
Department of the Army

October 1969

W A R N I N G

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CONTENTS

GLOSSARY

Alluvium — Deposits of waterborne earth materials laid down in stream beds, flood plains, lakes, and at the lower edges of steep slopes.

Drift — Any unconsolidated earth material deposited by glacial action or by meltwater from glaciers.

Wisconsin drift is drift materials deposited during the Wisconsin (glacial) period of the Pleistocene Age.

Esker — A ridge of gravelly or sandy drift deposited by streams in association with melting ice, generally under or on the ice itself.

Kame — A hill or short irregular ridge of gravelly or sandy drift materials deposited at the edge of a glacier.

Moraine — Earth materials (drift) moved and deposited chiefly by glacial action.

Ground moraine is an irregular sheet of drift deposited beneath a glacier.

Recessional moraine is a ridge or hill of drift, similar to a terminal moraine, formed during the shrinking or retreat of a glacier well within the outermost extent of glaciation.

Terminal moraine is a ridge or hill of drift deposited at or near the lower terminus of a glacier.

Outwash — Stratified drift materials deposited by meltwater beyond a glacier.

Terrace — A nearly level, narrow, plain surface with ascending steep slopes on one side and descending steep slopes on the other; usually formed of or covered with unconsolidated materials.

Till — Drift materials, generally nonsorted and nonstratified, deposited under glacial ice.

Till plains are fairly level sheets of unconsolidated materials (till) deposited without well defined structure or relief beneath a glacier.

ABSTRACT

This preliminary engineering study of a proposed Lake Michigan-Wabash River barge canal was conducted to evaluate the feasibility of constructing and operating a barge canal between Lake Michigan and the Wabash River. Conclusions of the study include recognition of several major problems for the proposed canal. Among these are providing an adequate water supply, getting water to the summit level of the canal, and overcoming the lack of good water storage sites.

SUMMARY

This study of the proposed Lake Michigan-Wabash River barge canal was conducted by the Engineer Strategic Studies Group (ESSG), Office, Chief of Engineers, for preliminary engineering planning, to determine the feasibility of this canal. Environmental information was compiled for the study area and elevations were determined and plotted along potential routes. Several possible routes were evaluated and compared, and one of these was selected for more detailed analysis.

For the selected route, sites were chosen for the locks, earthwork computations were made, water requirements were determined, and water supply and storage were evaluated. Major problems in the construction and operation of the canal are: providing adequate water supply, getting the water up to the summit level of the canal, and overcoming the lack of good water storage sites.

Because of the preliminary planning scope of this study, cost estimates and comparisons were not included. This preliminary study indicates that the proposed Lake Michigan-Wabash River barge canal is most probably not feasible because of the limited water supply that is generally available from July to October and the lack of good water storage sites.

LAKE MICHIGAN-WABASH RIVER BARGE CANAL

I. INTRODUCTION

1. History. The basic authorization for this project originated in March 1967 by a resolution of the Senate Public Works Committee. This authorization instructed the Corps of Engineers to study the feasibility of a cross-Wabash barge canal.

2. Authority. At a conference on 23 August 1967, the Chief, Office of Interoceanic Canal Studies, Directorate of Civil Works, OCE, requested that the Engineer Strategic Studies Group (ESSG) perform an in-house study for two proposed canals originating near Lafayette, Indiana, and terminating near Gary on Lake Michigan and near Toledo on Lake Erie. This was confirmed in an MR, subject: "Conceptual Study: Wabash-Lake Michigan-Lake Erie Canals," dated 23 August 1967, from COL Hughes, Chief, Office of Interoceanic Canal Studies, CW, to the Chief, ESSG.

3. Objective and Scope. The objective of this project is to ascertain the feasibility of the proposed Lake Michigan-Wabash River barge canal. This was to be accomplished by a preliminary study with limited to moderate detail. The scope of work was to select a route and accomplish preliminary engineering planning for the proposed canal without making detailed cost studies or examining the economic feasibility of the construction and operation of the canal. A recommended route for

the proposed canal is selected, and a preliminary engineering analysis is made concerning lock locations, excavation, water supply, and other general planning requirements. This report covers only the Lake Michigan-Wabash River Canal.

4. Design Criteria. ESSG was furnished the following design criteria by the Office of Interoceanic Canal Studies, OCE:

a. Canal width: 200 feet.

b. Canal minimum depth: 9 feet.

c. Minimum radius of curvature for canal alinement: 8,000 feet.

d. Locks: 84 feet wide, 600 feet long, with 12 feet of water over sills.

e. Maximum height of lock lift: 100 feet, but lower lifts of 25 to 50 feet may be more desirable.

5. Procedure. Medium and large scale maps, supplemented by aerial photographs, were used to study and evaluate the study area.

a. Three potential routes for the canal were selected and profiles were determined along these routes and connecting lines. Selection of these routes was based primarily on medium scale maps for the area. This allowed an overall perspective with a manageable number of map sheets.

b. Overlays showing cultural features, drainage patterns, land use, and engineering soils were prepared to reveal environmental conditions which are important for route selection.

c. The three profiles were compared, with careful consideration given to the elevations, the environmental data presented on the overlays, and the effects of cultural features. The recommended route is a combination of three routes (see Figure 1).

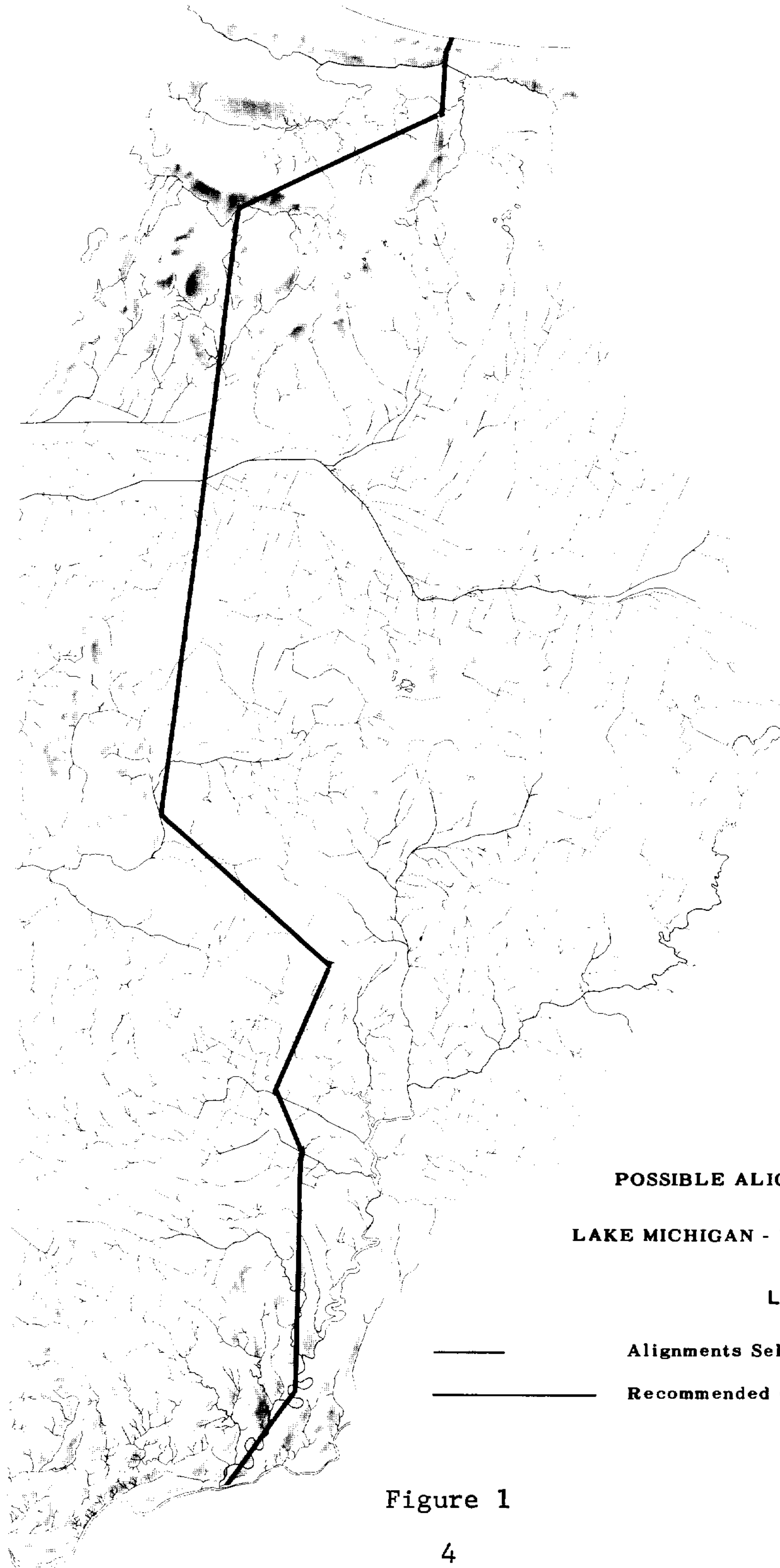
d. Preliminary engineering planning was made along the recommended route concerning the locks, water requirements, sources and storage of water, excavation, aggregate sources, and crossings of railroads and highways. A strip map overlay was prepared along the selected route, combining information from the other overlays.

II. OVERLAYS

6. Development. The following overlays were prepared: Cultural Features, Drainage, Land Use, Engineering Soils, Elevations, and Strip Map. These overlays were developed from topographic, geologic, highway, and other special map sources, supplemented by aerial photography. The six overlays and a shaded relief base at a scale of 1:250,000 are shown in Volume II of this report. For convenience, reduced copies of the overlays at a scale of about 1:625,000 are included in Annex B, this volume.

7. Cultural Features. This overlay shows urban areas, railroads, highways, and major streams. Town names and highway numbers were taken from an Indiana state highway map.

a. The town and urban areas are widely scattered over agricultural lands except near Lake Michigan. There are several cities near Lake Michigan, so potential canal routes are more restricted in that area.



POSSIBLE ALIGNMENTS FOR THE

LAKE MICHIGAN - WABASH RIVER CANAL

LEGEND

Alignments Selected for Evaluation

Recommended Canal Route

Figure 1

b. There are 12 railroads extending eastward from Chicago which must be crossed at the northern end of any route, plus four more crossings to the south. There is considerable rail traffic in this area, probably the heaviest of any section of the United States. Crossings where railroad and canal are at about the same elevation, requiring lift bridges, can cause considerable delays to both rail and canal traffic.

c. There is a dense highway network in northwestern Indiana, consisting of several major east-west federal highways and well paved state roads, plus county roads that crisscross the area in east-west and north-south directions, usually one-fourth mile apart. Many of these county roads would have to be blocked at the canal, but bridges should be provided at convenient intervals. Bridges should be provided for all the federal and state highways.

d. All major streams are shown on the Cultural Features overlay. The largest of these streams is the Wabash River, which is rather shallow and is not presently adequate for navigation either above or below Lafayette. To develop the full potential of a barge canal system servicing Lafayette, the Wabash River would have to be canalized upstream and connected to the Maumee River and Lake Erie, and/or the lower Wabash would have to be deepened and improved all the way to the Ohio River. The Tippecanoe River has been dammed at two points to form Lake Freeman and Lake Shafer, which are used for swimming, fishing, and boating. In the past, the Kankakee was a sluggish, meandering stream, but it has now been straightened and dredged so that a broad ditch cuts across the previous meanders in the study area.

8. Drainage. This overlay shows the detailed drainage pattern over the proposed canal area. Much of the rather flat, undulating surface does not drain very well, so an extensive system of drainage ditches has been constructed to supplement the natural drainage over large areas. This results in many straight, angular drainage lines which are not found in natural drainage patterns. Underground tile drainage systems are located in many of the areas where surface runoff is poor. A drainage map, prepared from aerial photography and published by Purdue University, covers the entire area. The Purdue map compilation extended over a period of several years and involved hundreds of aerial photographs.

9. Land Use. This overlay shows the land use and general types of vegetation in the area. Most of the area is agricultural and is representative of some of the best and most valuable farmland in the nation. Only in the vicinity of Gary and Valparaiso is there much difficulty in routing the canal outside urban developed areas. Use of the land has been very highly developed. Eighty-one percent of the area is under cultivation, 12 percent is covered with forest and brush, 2 percent is grass-covered, and 4 percent can be classified as urban and industrial development. Less than 1 percent of the land is barren or water-covered.

10. Engineering Soils. The entire region covering this portion of northwestern Indiana has been subjected to continental glaciation which is reflected in its soil and geologic conditions. The original rock surface has been covered with glacial drift materials. The southern portion of the area consists primarily of a rather level ground moraine (or till plain of the Wisconsin age). This Wisconsin ground moraine has a light-dark mottled pattern. In the central part of the study area in the Kankakee basin and southward the ground moraine was covered by sand and gravel outwash deposits as the glacier melted and receded to the north. Subsequently, much of the sand has been developed into dunes by wind action. A rather straight ditch has been dredged through the meandering Kankakee River, probably to provide better drainage. North of the Kankakee is a recessional moraine, a rolling surface similar to a terminal moraine but which has been formed during the recessional stage, well within the outermost extents of the glaciation. Between the moraine and Lake Michigan are some high sand dunes and long sand beach ridges paralleling the shore of the lake. There is a narrow beach along most of the southern edge of Lake Michigan, but since the scale of the overlays is so small it is included in the area mapped as dunes. In addition, there are small areas of kames, eskers, and organic deposits scattered on the outwash plains and ground moraines. Also there are small granular terraces and sand or silt alluvial plains along the Wabash and Tippecanoe Rivers.

a. In general, the Engineer Soils overlay shows only the surface soils. Some of the boundaries of these soils are indefinite as it is very difficult to determine a specific boundary, for example, where deep sand becomes shallow and gradually diminishes to leave ground moraine at the surface. An area covered with sand only a few inches thick could justifiably be mapped as sand or as the underlying material. For this project, much of the area which was covered by shallow sand was not identified as sand, but rather as the underlying material since the engineer would be primarily concerned with this.

b. On the overlay the landforms have been mapped (identified by a letter), giving an indication of the original material. The usual composition of these soils is also shown by symbols. Outwash was generally mapped as sand and gravel; ground moraine as silty clay; however, several areas mapped as outwash and ground moraine are shown as sand because the indications are that the surface retains the features of the underlying material but is covered by a significant although shallow layer of sand. This may be the result of wind action but may not be deep enough to be considered as dunes. From the Kankakee River for 15 to 20 miles south, the surface is covered with sand from deep to shallow, even though some of it may not be indicated as sand on the overlay.

c. Depth of the glacial deposits to the underlying bedrock is believed to be rather large (50 feet or more) over most of the area. There are several rock quarries and gravel pits where the shallow drift cover has been removed and the underlying material is being excavated. Limestone is being obtained from quarries located east of Rensselaer and south of Francesville. The recommended route passes between these quarries.

11. Elevations. Ground elevations were determined at 500-foot intervals, along the routes shown in Figure 1. In order to present a more graphic view of elevations along these routes, the positions were plotted and elevations listed at horizontal intervals of approximately 3,500 feet. These are shown on the Elevations overlay, Figure B-5 of Annex B. This enables one to compare approximate elevations rapidly over all the routes. Letters are used to identify line segments.

12. Strip Map. An additional overlay was prepared with a strip map about 5 miles wide along the recommended route showing the cultural features, major streams, soil boundaries, railroads, and highways, proposed lock locations and other relevant data. This consolidates much of the significant data which is needed to make the more detailed analysis of the recommended route.

III. ROUTE EVALUATION

13. Topography.

a. Good topographic maps are available and there is complete photographic coverage for the area. However, the time limit and preliminary planning scope of this study did not justify the collection and analysis of the thousands of photographs required for complete coverage. Profiles of the surface elevations were determined along three potential routes and three lines transverse to these routes (see Figure B-5, Annex B).

b. The study area can be partitioned on the basis of topography with respect to an east-west line described by the south rim of the Kankakee River valley. Directional aspects of topographic features in the northern part of the study area are distinctly different from those in the southern part, and both types, according to their peculiar characteristics, exert considerable influence on initial selections of desirable alinements of north-south canal routes. The dominant features in the northern part, the beach ridges and sand dunes, the moraine ridge extending through Valparaiso, and the Kankakee basin, lineal in form, lie transverse to the direction of prospective canal routes. South of the Kankakee valley is a broad upland area which has a rather level to undulating surface that gradually increases in altitude to the southwest. There are sand dunes near the Kankakee, but to the south there are few topographic breaks except for scattered kames and eskers. The Tippecanoe flows southward along the eastern side of the study area. The upland drops off rather steeply to the Tippecanoe valley and also to the Wabash valley at the southern edge of the study area.

14. <u>Route Selection</u>. One route has been selected as preferred among those under consideration. This selection was based primarily on key

environmental conditions and a comparison and evaluation of the construction problems and work effort for the proposed routes. Economic factors were given some general consideration, but no cost studies were made. Consequently, there was no way of accurately comparing the costs of various types of construction and operation, such as the cost of elevating railroads versus the cost of additional excavation to lower the canal.

a. The best terminus for the canal at Lake Michigan is at Burns Ditch. Farther to the west, urban and industrial areas would be encountered. To the east are high sand dunes and higher elevations of the moraine to the southeast.

b. An important consideration in this area is the 12 railroads that the canal will cross within 18 miles of Lake Michigan. There is so much heavy traffic on these lines that crossing of the railroads with the canal level near the elevation of the tracks appears to be impractical. The railroads could be elevated on fills to bridge over the canal, however, these fills would create major problems at other transportation intersections and for rights-of-way through nearby urban areas. It was concluded that it would be best to keep the canal surface low enough to pass under most of these railroads with little or no raising of the existing railroad tracks. There are three lines, however, about a mile from the shore of Lake Michigan where the canal level will be at the elevation of the lake and the tracks will be only about 10 or 15 feet higher. These tracks provide access to port and industrial facilities near Burns Ditch and extend to other rail centers to the east. If traffic justifies it, these tracks should be raised to bridge over the canal with adequate clearance; if not, movable span bridges should be provided. There are two saddles in the recessional moraine on which most of these railroads are located that have surface elevations considerably lower than the rest of the ridge. The amount of excavation will be reduced if the canal were routed along line R-S through the saddle near Crown Point.

c. The crossing of the Kankakee River valley could be made with the canal at the elevation of the river or it could be taken across on a fill and bridged over the river. The decision on which type of crossing to use has considerable bearing on the alinement selection because of the decreasing elevation of the Kankakee valley to the west. It was concluded that fewer problems are likely to be encountered with the canal on an embankment bridged over the river than with an intersection of the canal and the Kankakee at the same elevation. Crossing the valley at summit level will provide sufficient clearance for flood waters to pass beneath the bridge without structural damage or flow restraint.

d. Data on the overlays were considered in the route selection. The only area where land use was very restrictive was near Lake Michigan where urban areas and industrial plants are numerous. There are several types of soil in the study area, but they extend generally in broad belts in an east-west direction. No matter which route is taken, the same soil belts will have to be traversed. There are extensive sand areas near Lake Michigan and also south of the Kankakee River. Seepage from the canal could be a major water supply problem through these sand areas, or the canal might lower the adjacent water table. The sand probably is a little less extensive along the westernmost alinement under consideration. There are some constraints in crossing the southwestern part of the upland plain, where elevations near the Wabash valley are higher.

e. The sides of the Wabash valley rise steeply for about 150 feet, making it inadvisable to bring the canal directly up from the Wabash River. Two large gullies extending from the lower Tippecanoe valley offer suitable routes with a more gradual change in elevation where locks can be located.

f. The route through points A, B, R, S, T, Y, Z, F, P, H, and J (see Figure B-6, Annex B) was selected as the recommended route based on the careful consideration of pertinent factors that could be determined within the limits of this project. The route combines the best topographic conditions for allowing the canal to pass under nine railroads within 20 miles with little or no change in existing railroad grades and to be bridged over the Kankakee River at the summit level.

IV. ENGINEERING ANALYSIS

15. General. Some of the basic principles of canal design are discussed briefly to point out the factors which are important, such as lock locations and sizes, pool elevations, and potential water sources. Significant features are then described briefly as they relate to the route selected for more detailed study.

16. Design Principles. Determination of the canal profile, as in the case of alinement selection, was based on judgment governed by major technical considerations and the application of general principles relating to the effect of certain design aspects on costs. In the selection of locations and elevations, features of the design affecting the travel time through the canal were borne in mind as were the general relationships of possible costs for initial construction and for operation and maintenance. The profile as finally determined was based mainly on principles relating to the three major design elements: locks, pool levels, and the crossings of major features. Design options available in the crossings of major features are so closely interrelated with pool levels that the two elements were considered together. Discussion of the principal factors considered in determining locations, sizes, and elevations of locks and pool levels follows.

17. Locks.

a. The number of locks should be kept to a minimum in order to minimize the total travel time through the canal. The fewer the number of locks, however, the higher the lift of individual locks and the greater the total water requirement. Design costs may increase significantly for lifts above 40 feet. Hydraulic model tests are recommended for locks between 40 and 75 feet and are normally required for locks of 75 feet or higher.

b. Locks should be located where changes in the elevation of the natural ground permit economical construction; however, locks should be separated by a distance sufficient to offset excessive fluctuations in the water level in the pool above the lock. Although location of locks are influenced by changes in elevation of the natural ground surface, they are also affected by the requirement for water storage in the pool above the lock. Distances between locks should be maximized to minimize fluctuations in water levels both above and below the lock. In general, higher locks require greater pool lengths; however, where pool widths can be increased, distances between locks may be lessened.

c. Where water for a series of locks is supplied from summit level pools, lock heights should be equal throughout the series. The water requirement for lock operation in a series of locks is determined by the largest lock in the series. Water sources below the summit level might be used to supplement summit level supplies to larger locks that are lower in a series. With the sole source of water supply at the summit level, if locks of different heights are necessary and each is separated from the other by a storage pool, an advantage might be gained in some cases by arranging the series in decreasing order of magnitude from the highest to the lowest elevation.

18. Pool Water Surface Elevation.

a. Elevations of pool surfaces, especially the surface of the summit pool, should be chosen to permit gravity flow from water sources if possible and to minimize the head where pumping to storage from the source might be required. Although lower summit levels might reduce operating costs for pumping as well as the overall water requirement, the increase in construction costs due to deeper excavation and possibly an increase in the difficulty of excavation might tend to offset a saving in pumping costs.

b. Pool water surfaces should be generally at the same levels as the natural ground water. The average ground water levels may impose a limit on the range of feasible elevations for the canal water surfaces. Excessive seepage losses can be incurred where pool water surfaces are perched above the ground water levels. Where the canal water surface is lower than the water table, drainage of ground water into the canal can cause a general lowering of the ground water level and could have adverse affects upon agriculture in the vicinity of the canal.

c. It is normally best to pass highways and railroads over the canal and to pass the canal over drainage lines. Bridges for highways should be erected to allow uninterrupted movement of canal traffic; minor roads would not cross the canal. Railroad bridges, depending on the frequency of rail traffic and the feasibility of designs for bridge approaches, should allow uninterrupted movement of canal traffic. Movable-span bridges for railroads might be erected where rail traffic is relatively infrequent and where technical problems render fixed bridge crossings infeasible. Consolidation of several railroads at bridge crossings might be economically advantageous in some cases. Minor streams could be intercepted and channeled underneath the canal or, where silt loads could be adequately controlled, diverted into the canal. Construction of a canal bridge is the method normally advocated for crossing rivers and major streams. Intersection of a navigation canal with a river at the same level introduces complex hydraulic analysis and design problems and would probably result in costly structures for flood protection and control of the river.

19. Profile Design. The design profile for the recommended alinement, shown on Figure 2, was developed through judgment in the application of the design principles discussed previously. It represents a first step toward approximating an economical overall design within one concept considered to be feasible and provides a basis for computing excavation quantities and water supply requirements. The pool elevations and

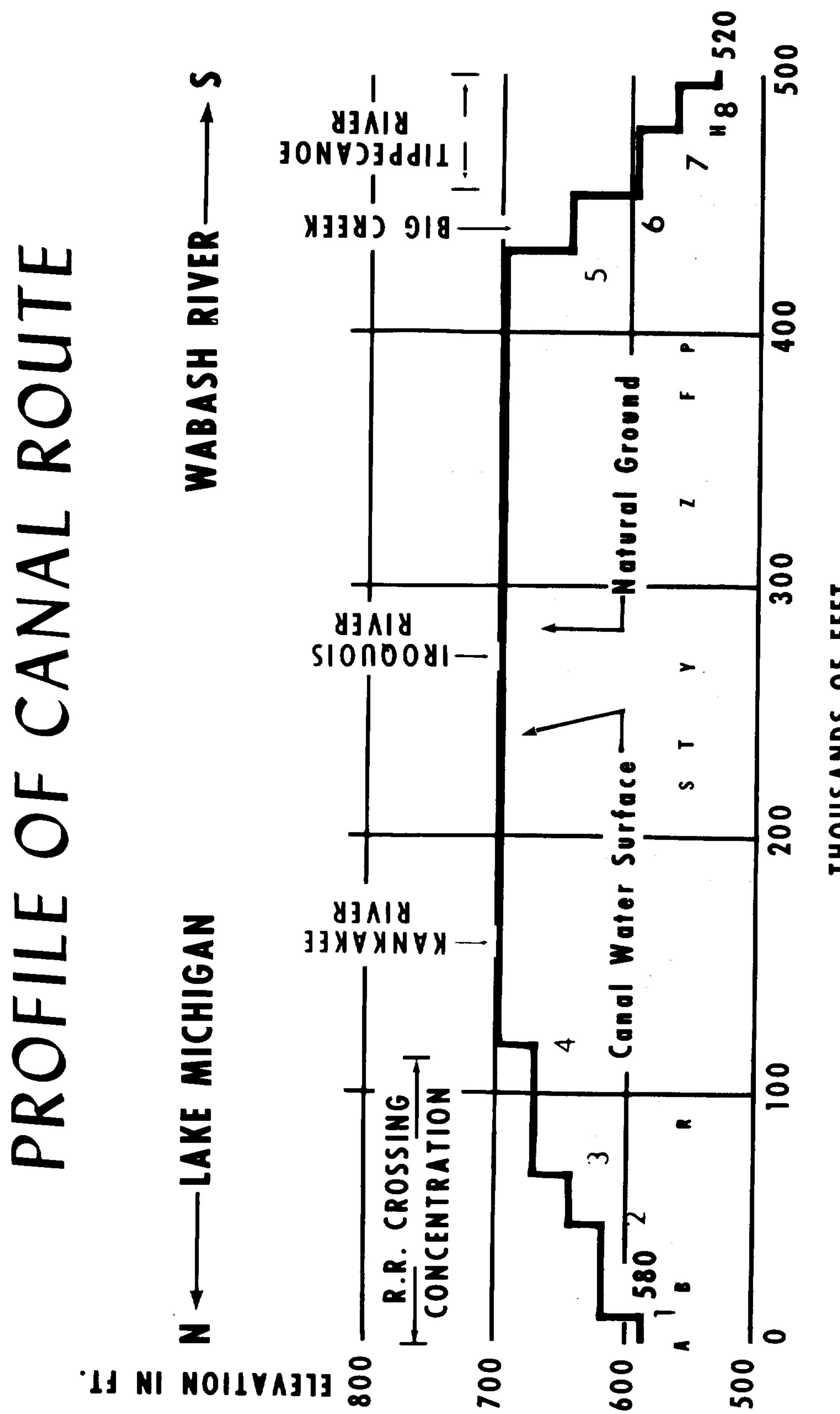

PROFILE OF CANAL ROUTE
N ← LAKE MICHIGAN
WABASH RIVER → S
ELEVATION IN FT.
800
700
600
500
R.R. CROSSING CONCENTRATION
KANKAKEE RIVER
IROQUOIS RIVER
BIG CREEK
TIPPECANOE RIVER
Canal Water Surface
Natural Ground
580
520
1
2
3
4
5
6
7
8
A B R S T Y Z F P H
0
100
200
300
400
500
THOUSANDS OF FEET

Figure 2

placement of locks were chosen primarily to effect a balance between requirements for excavation and elevation of railroad crossings. Simultaneous consideration was given to the height and number of locks to provide a logical compromise between the water requirement and time required to traverse the canal route. Care was taken in the spacing of locks to allow storage sufficient to offset extreme fluctuations in pool surface levels. In the choice of the summit pool elevation, which in a final analysis would be strongly influenced by the natural ground profile and ground water, no official records of ground water were consulted; instead, the assumption was made that ground water levels were relatively close to the ground surface during most of the year on the basis of the flat topography and the artificial surface drainage development over much of the area, as well as scattered subsurface drainage installations.

a. The elevation of Lake Michigan is 580 feet above mean sea level. Locks must be provided to get the canal across the east-west moraine, which has a minimum elevation of about 690 feet. The crossing of 11 railroads, most of them on the moraine ridge, must be considered in getting the canal through the moraine. In the Kankakee valley, along the river at points of intersection of the potential routes, the elevations range from 650 to 660 feet, west to east. The Kankakee valley could be crossed with the canal on a fill, which would carry the canal over the river. South of the Kankakee, the upland elevations generally vary from 680 to 700 feet with a few places beyond these limits. Then, locks must be provided to get the canal down to the Wabash River elevation at about 520 feet.

b. There are three railroad crossings within 2 miles of Lake Michigan which are about 10 feet above the elevation of the lake. These railroads service industrial and port facilities and also extend to other urban areas. Approaches on fill which will yield bridges with adequate canal clearance or movable span bridges, whichever is most feasible, must be provided for these crossings. A drawbridge is not believed to be practical over the canal if there is very much rail traffic on the line, as there would be many interruptions and delays in rail and canal traffic.

c. The number and positions of locks at the north end of the canal were selected primarily with respect to existing major land transportation route crossings on the moraine to the north. Lock positions were chosen to allow the canal to pass beneath the railroads with little or no elevating of tracks and still give a 40-foot overhead clearance on the canal. The additional excavation to do this was weighed against the reconstruction necessary to elevate the tracks of the eight railroads which must be kept at a very low gradient and the problems of getting additional right-of-way to provide fills through nearby urban areas. Three locks of 25-foot height will pass the canal under the railroads which traverse the moraine. The fourth 25-foot lock was added on the south side of the moraine to bring the canal to the summit level for the crossing of the Kankakee River.

d. The basis for the placement and height of locks toward the south end of the canal was oriented primarily toward minimizing the quantity of excavation, although water supply, pool storage, and other factors were considered as well. The total lift from the Wabash River (elevation 520 feet) to the summit level (680 feet) is 160 feet. Within the total lift, the portion along the Tippecanoe depends on the number of dam sites, the feasible heights to which dams may be constructed, and whether the first upstream hydroelectric plant would be conserved. It was possible to estimate that a pool surface of approximately 580 feet elevation would be within the limit allowable for preserving the upstream power site. Two proposed dam sites were selected on the lower Tippecanoe. It was determined that each of these dams would permit a 30-foot lock lift for the reach from the Wabash River to the south end of the canal. The two 50-foot locks on the canal route, which complete the total lift to the summit level, were selected primarily to conform to the topography as indicated by the natural ground profile.

20. Kankakee Valley and River Crossing. A study of the profiles indicated that the most feasible elevation to traverse the upland area south of the Kankakee River was at 680 feet. Several important factors had to be evaluated in selecting the summit level: (1) low summit level will reduce the total amount of lift and the problem of getting water up

to that level; (2) amount of excavation will be reduced by keeping the canal surface a few feet above the ground surface; (3) seepage would be reduced if the canal surface were near the ground water level; and (4) the relative elevation of the Kankakee River. South of the Kankakee, the canal crosses only four widely separated railroad tracks in mostly rural areas, so railroad crossings have less importance here.

a. The most desirable crossing scheme for the valley is with the canal on a fill and with a canal bridge over the river. Crossing the Kankakee valley at river level to avoid the construction of a large embankment would involve structures for river regulation and flood control which could be more costly to build and maintain. The canal bridge may be built as two separate channels to avert the hazard of vessels passing in opposite directions. The water surface and depth would correspond to the water surface and depth of the summit pool. The canal approach at each end of the bridge would be elevated by means of an embankment, built over the low ground of the wide valley. The canal section within the embankment would be the same shape as that of sections excavated in natural ground. The valley can be crossed at the summit pool level of 680 feet with an adequate clearance beneath the canal bridge for flow of the Kankakee River. The profile elevation adjacent to the Kankakee River was 650 feet (however, elevation of high water, interpolated on the basis of USGS records for gages to the east and west of the proposed canal crossing, was determined to be 646 feet).

The vertical distance between high water of the river and the bottom of the bridge channel is 23 feet, which must provide for the thickness of the supporting bridge structure and adequate clearance for flood waters.

b. At first thought, it may seem unusual to carry the canal across the Kankakee valley on an embankment, but this arrangement is not without precedent since a considerable section of the existing Erie Canal is on a 50-foot fill. When compared with the problems encountered by crossing the river with the canal at the same level, the canal bridge and fill seem to be the most feasible method. Two other concepts considered for crossing the Kankakee valley were rejected as they did not appear to be practical. Both involved creating a reservoir in the Kankakee valley. In one case, the Kankakee River might be crossed through a navigable pool formed by damming the river downstream from the canal route crossing. In the other case, the river flow might be regulated by a dam upstream of the canal crossing. In the latter concept, the river would pass beneath the canal under a smaller bridge. A major advantage in either of these concepts would be the impoundment of Kankakee River runoff for use in the canal. Damming the Kankakee would result in the flooding of vast fertile farming lands in this broad valley, and small surface level fluctuations might expose large areas of the bottom or create large areas of undesirable shallow depths. Much of the valley consists of a sandy soil which might allow the water in a reservoir to seep around and under the impounding dam.

21. Water Requirements.

a. The canal requirements for water during the navigation season (assumed to extend from the beginning of April to the end of November) includes amounts for lock operation, losses in the waterway, and losses from storage reservoirs. The requirement would vary with the amount of reservoir storage developed for supply during dry periods. Theoretically, losses from reservoir storage could range from a minimum of zero at times where source flows might be adequate for the canal needs without storage to a maximum where the total canal requirement was provided from storage. Water can be conserved when supplies are inadequate by providing systems for reusing some of the water: thrift locks which retain part of the water at upper levels for reuse in subsequent fillings of the same lock or a system of recycling water back to higher levels.

b. All flow requirements for the canal were computed on the basis of 20 lock operations per day. The minimum canal flow required for 20 lock operations, without considering storage reservoir losses or assuming that no storage would be required, was estimated to be 1,250 cubic feet/second. The estimated loss from reservoirs to supply the waterway evaporation and seepage losses would raise the flow requirement to 1,290 cubic feet/second. If it were feasible to provide reservoir capacity to supply the total flow required by the canal for a maximum period of 4 months, the additional loss would raise the flow requirement to approximately 1,380 cubic feet/second. The following tabulation summarizes computed flow requirements for the canal with the exception of the requirement to replace losses from storage reservoirs (Figure 3). Methodology for computation of water requirements for lock operations, water losses, and storage are presented in Annex C.

COMPUTED CANAL WATER REQUIREMENTS

Canal Water Requirements	Flow (c.f.s.)
Operation of North Locks	290
Leakage Through North Locks	20
Operation of South Locks	580
Leakage Through South Locks	20
Evaporation and Seepage from Canal	270
Evaporation from Pools Above Dams	70
Total	1,250

Figure 3

22. Sources of Water. Major problems must be overcome in selecting adequate sources of water for the canal, pumping water up to the summit level, and storing water to insure operation during the dry season. Storage must satisfy the waterway demand for at least 4 months of the navigation season during which low flows may prevail. The flat

topography does not provide many suitable sites for water supply storage. Reservoir sites of the size indicated necessary by estimated storage requirements could probably be formed only by inundating large areas of valuable farmland, resulting in the exposure of large mud flats during low stages. Elevations of water supply sources, relative to those for the canal summit pool, indicate the necessity for pumping a large part of the canal requirements. Stream flows vary considerably from wet to dry years. In some years the flow from the several sources may not be adequate to provide for the canal needs and at the same time satisfy other important demands such as sanitation and power generation.

a. Potential sources of water for use in canal operations were analyzed. Evaluation of water supply sources should be based on reliable stream flow data and a knowledge of other present or planned uses of individual water sources. Consideration of present uses was limited to those most obvious, such as the indicated use for power generation. Only a general evaluation of sources was possible which indicates those being relatively good or poor as a supply potential.

b. Lake Michigan is a potential source of water of almost unlimited supply, even during years of low rainfall. The Wabash River seems to have the greatest potential of any river in the area, but it is 160 feet below the summit level of the canal. The Tippecanoe and Kankakee Rivers offer significant but more limited supplies of water. Both these rivers are lower than the canal summit level. The level of

Lake Shafer on the Tippecanoe could be raised by building a higher dam, leaving only 10 to 20 feet for this water to be pumped to the summit level. Water from the Kankakee would have to be pumped about 30 feet unless a reservoir was provided which would flood a very large area. Other potential sources appear to be rather insignificant. There are several small streams and lakes which appear to offer little potential. Possibilities of transporting water to the summit level of the canal by gravity flow are not good. The best possibility seems to be a somewhat limited amount from the Tippecanoe River some distance upstream to the northeast of Lake Shafer. Hydrologic data were obtained from reports of the USGS to make a general analysis of the water supply potential, as described in Annex A, Stream Flow Data.

c. The availability of water and the elevations of potential sources in relation to the summit elevation of the canal are crucial factors in this project. Extended dry periods during late summer and early fall affect the availability of water from streams in the area. The data in Annex A indicate that stream flows are considerably below the average from July to October and they are extremely low in about 1 year out of 5, which would result in critical water supply problems for the operation of the canal. Considerable water storage facilities or systems for reusing water will be necessary to insure continued operation of the canal through extended periods of low flow in the rivers.

It is evident that facilities will have to be provided to bring water from several sources to the canal.

23. Storage of Water. The topography of the area does not lend itself well to the development of reservoirs for water storage. Only major potential water storage sites were considered. In general, because of the usually saucer-shaped cross sections of the valleys in the area, it appears that development of reservoirs, with capacities and depths adequate for the project canal, would cause the inundation of broad areas of valuable cultivated land and the exposure of large mud flats at low reservoir levels.

a. The sites of two existing reservoirs found within the banks of the lower part of the main portion of the Tippecanoe River seem to hold potential for additional storage; however, from a practical standpoint the lower one, Lake Freeman, would probably be limited to its present levels because of probable inundation of part of the city of Monticello and interference with two railroads at its upper end. The upper reservoir, Lake Shafer, is bordered primarily by individual homes and cottages. It was estimated that the level of the upper reservoir could be raised approximately 20 feet, which would provide a storage volume of approximately 30,000 acre-feet. The narrow width between banks of the river above Lake Shafer and the shallow valley of the main river and tributaries offer no good opportunities for reservoir storage. Development of a broad shallow reservoir on the main river just above Ora might be feasible where topography is more rolling.

b. Storage within the Kankakee River might be provided with a large reservoir formed by a long dam across the valley, upstream from the proposed canal crossing; however, such a reservoir has several obvious disadvantages. A large reservoir in the Kankakee valley would inundate over a hundred square miles of valuable farmland, probably require major relocations of transportation facilities, and form vast mud flats and possibly marshes along its banks at low stages. Because of the considerable areas of sand in the Kankakee valley, the possibility of excessive loss of water by seepage from the proposed reservoir must be considered. The Kankakee valley is the only site for a large reservoir that could meet the storage requirements for the canal. The total volume of all other potential reservoirs is far less than the potential capacity of one on the Kankakee. A rough estimate, based on two profiles across the site, indicates that a Kankakee reservoir would have a storage capacity of about 1,300,000 acre-feet with the water surface at an elevation of 670 feet and would probably require 3 years to fill at one-half the normal flow. This should allow at least 500,000 acre-feet to be withdrawn from the reservoir, which would be adequate for operating the canal over a prolonged 6-month period of low flows.

c. Dams on the Wabash River would probably be restricted to low structures forming only shallow pools, such as those required for navigation, in order to limit river levels and thereby preserve the existing agricultural areas and towns developed within the high steep sides of the river valley. For this reason, as well as the relatively low elevations of the main river, development of the Wabash River itself was not considered for storage sites. The upper reaches and tributaries of the Wabash, outside the study area, might hold some potential for storage; however, supply from reservoirs along the Wabash would present problems because the feasibility of gravity flow to the summit of the canal seems to be doubtful and in the vicinity of the canal supplies from the Wabash River to the summit of the canal would require pumping to a height approximately 160 feet above the river.

d. Storage possibilities on the St. Joseph River were not investigated as its location is beyond the limits of the study area.

e. The basin of the Yellow River above the gage at Knox, Indiana, is typical of the broad shallow valleys of the study area. A reservoir for storage in this valley would be characterized by a large surface area in relation to its average depth.

f. A depth of 11 feet was selected for the canal, 2 feet above the specified 9-foot depth, to allow for fluctuations in water levels during operation and for storage to offset interruptions in day-to-day operations. The additional 2 feet of depth would provide storage enough for approximately 1.4 days of operation. The topography adjacent to the canal at the summit level does not contain suitable sites for large reservoirs. Storage at the summit level of the magnitude necessary for canal operation over any appreciable part of the 4-month period of low flows does not appear to be feasible.

24. Reuse of Water. Because of the limited amount of water available at certain times of the year, the few good water storage sites available, and the problem of getting the water to the summit level, systems of conserving and reusing water were considered. Two systems which could significantly reduce the total amount of water that must be provided from the several sources are thrift locks, which store water in shallow basins adjacent to the lock for reuse in subsequent lockages, and a recycling system, which would pump water from lower levels in the system to be used again in filling the locks. Unless some system of conserving and reusing some of the water is provided, it is doubtful if the normal operations of the canal can be continued through the extremely dry periods which have occurred at intervals of 5 or 6 years. A discussion of thrift locks and recycling systems is presented in Annex D, Water Conservation.

25. Evaluation of the Total Water Problem. As noted in the previous paragraphs, major problems will be encountered in selecting adequate sources of water, storing enough for operation through the dry season, and pumping water to the summit level of the canal from the potential sources which are mostly at lower elevations. The St. Joseph River, 60 miles away, is the only source where any substantial amount of water might be obtained by gravity flow and its availability is questionable. All other major potential sources will require pumping the water considerable heights to the summit level: 20 to 30 feet from

the Tippecanoe, 15 to 30 feet from the Kankakee, 100 feet from Lake Michigan, 160 feet from the Wabash. Since much of the water will have to be pumped even for normal operation, it appears that a recirculating system to conserve supplies could be provided which would not add much to the cost of operation. Water for operation of the northern locks might be taken from Lake Michigan and/or the St. Joseph River, to be returned to the lake after its use. In normal years the use of about half the water from the Tippecanoe and Kankakee Rivers is probably sufficient for operation for about 4 months of the 8-month navigation season. During the other 4 months, these stream flows will provide only part of the water needed, probably less than half. The rest will have to come from storage reservoirs or by reusing some of the water. Raising the dam at Shafer Lake will provide only about 30,000 acre-feet of the 330,000 acre-feet of storage which may be needed to operate through the dry season. For the drier years the period of low flow may last longer than 4 months and the required storage could be greater than this. The only potential method of storing a large volume of water is by damming the Kankakee River, which would flood a vast area of cultivated farmlands. There are not sufficient good sites for small reservoirs which, together, would store as much as a reservoir on the Kankakee. In about 1 year out of 5, flow for the year could well be below normal and very little water could be diverted from any of the rivers for canal operation or storage. Total flows for the year may not meet annual canal requirements. A recycling or thrift system should be provided for reusing some of the water to insure continued operation during extended periods of low flows. If for some reason a reservoir cannot be established on the Kankakee River, there does not appear to be any other possibility of storing enough water to insure operation through the driest years. Even with a recirculating system for reusing some of the water, some "new" water must be added continuously to counteract pollution. There are a number of ways of providing water for the canal, which would have to combine several of the potential sources. Final decision would be based on the economics of making use of the available water. It is most probable, however, that it may not be economically feasible to construct and operate the canal because of the difficulty of providing adequate supplies of water in the years of low flows and the cost of pumping extremely large volumes of water.

V. CONSTRUCTION FEATURES

26. Earthwork. Computations were made to determine the approximate amount of earthwork for the project. These computations are based on a canal with a water depth of 11 feet, bottom width of 200 feet, canal side slopes and cut slopes of 1:2, and fill side slopes of 1:3. All elevations given for the canal are the elevations of the water surface. Typical cross sections are shown in Figure 4. Cross section elevations away from the centerline of the canal were not calculated and are assumed to be the same as centerline elevations. Computations were made along the

TYPICAL CROSS SECTIONS

VERTICAL EXAGGERATION 2 : 1

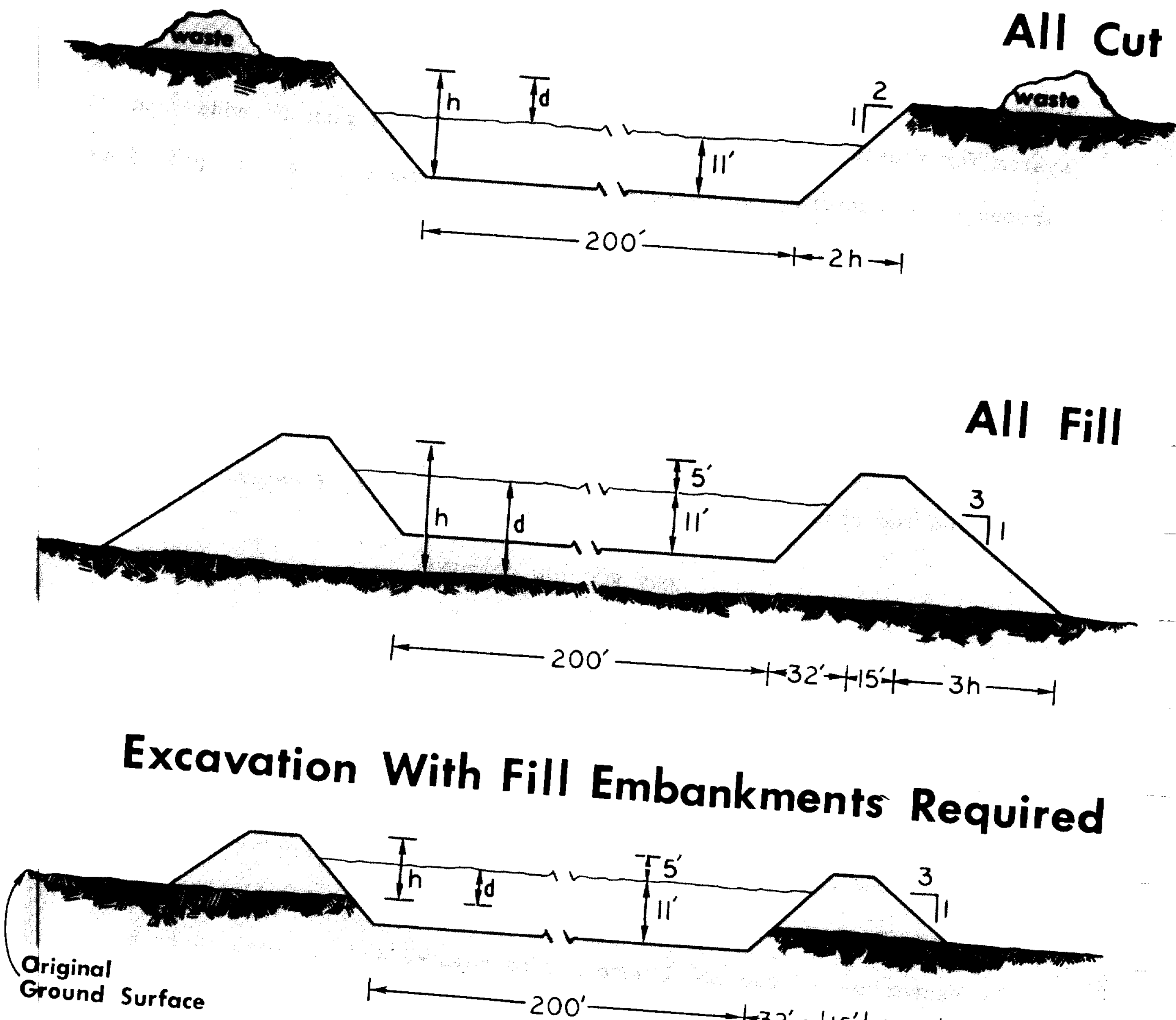


Figure 4

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tangents at curves, as elevations were not determined on the arcs. Errors caused by these procedures are relatively minor, particularly since a final alinement selection would at least modify the recommended route based on more refined data. Net volumes of cut or fill for each segment were approximately calculated by determining the difference between the average natural ground elevation and the canal water surface elevation, calculating the corresponding cross sectional area, and multiplying that area by the length of the segment. Average natural ground elevations for each segment were estimated from a profile developed from elevation readings at 500-foot intervals. Segments were selected as convenient lengths based on turning points, locks, and significant changes in the profile. Although the elevation of the canal (water level) may be above the ground surface, there may be "cut" required because the bottom of the canal is 11 feet below the water surface. Most of the excavated material is expected to be "wasted" along the sides of the canal. Along some segments, material is needed to provide banks along the canal that are at least 5 feet above the water level. Some of the cut material can be used where fill is required, although the haul distances may be 7 or 8 miles to the center of the Kankakee valley. A table showing the cut and fill computations is shown in Figure 5. Little, if any, rock excavation will be encountered, although this cannot be definitely determined from the preliminary data. The bedrock has been covered with a mantle of glacial drift materials, which is probably 50 feet or more in depth tangents at curves, as elevations were not determined on the arcs. Errors caused by these procedures are relatively minor, particularly since a final alinement selection would at least modify the recommended route based on more refined data. Net volumes of cut or fill for each segment were approximately calculated by determining the difference between the average natural ground elevation and the canal water surface elevation, calculating the corresponding cross sectional area, and multiplying that area by the length of the segment. Average natural ground elevations for each segment were estimated from a profile developed from elevation readings at 500-foot intervals. Segments were selected as convenient lengths based on turning points, locks, and significant changes in the profile. Although the elevation of the canal (water level) may be above the ground surface, there may be "cut" required because the bottom of the canal is 11 feet below the water surface. Most of the excavated material is expected to be "wasted" along the sides of the canal. Along some segments, material is needed to provide banks along the canal that are at least 5 feet above the water level. Some of the cut material can be used where fill is required, although the haul distances may be 7 or 8 miles to the center of the Kankakee valley. A table showing the cut and fill computations is shown in Figure 5. Little, if any, rock excavation will be encountered, although this cannot be definitely determined from the preliminary data. The bedrock has been covered with a mantle of glacial drift materials, which is probably 50 feet or more in depth in most places. There are two limestone quarries located near the recommended route between points Y and Z. At one of these quarries, about 10 or 15 feet of drift material has been removed to get down to the rock surface. Near these quarries, however, elevation of the recommended alinement is above the ground surface, so the canal might cross this shallow drift without getting down to the bedrock.

27. Aggregate Sources. Aggregate will be needed primarily for the construction of the locks. There are several areas that are potential sources of good aggregate:

a. Granular terraces along the Wabash and lower Tippecanoe Rivers with good gradation of both sands and gravels.

b. Kames and eskers throughout the area which should be a good source of both sand and gravel.

c. Outwash plains that consist of sands and gravels.

d. Limestone which can be crushed and used for coarse aggregate where the limestone is near the surface.

e. Dunes consisting of sand, although usually of a uniform size and poorly graded for use in concrete (beach ridges would be a better source).

The existing quarries and gravel pits are shown on the Soils overlay, Plate B-4 and the Strip Map overlay, Plate B-6. The most promising locations for establishing new aggregate sources are the areas marked on the Soils overlay with W, K, and T. Borrow material, preferably fine-grained impervious material, will be required for the embankment across the Kankakee valley. This material can probably be obtained from the canal excavation through the moraine north of the Kankakee.

28. Urban Areas and Relocations. The recommended route avoids urban areas. The vicinity of Gary was the only region where urban development had a very restrictive effect on the alinement. The route passes rather close to two small towns, Demotte and Leroy, but the canal could be shifted a mile or so if desirable with very little effect on the construction effort. There will have to be many new railroad and highway bridges built to cross the canal, but construction of the canal will not affect many existing bridges.

a. There are three existing railroad crossings across Burns Ditch within 2 miles of the shore of Lake Michigan. These will have to be replaced with new bridges elevated on fills or with drawbridges, as the canal will be much wider than the existing ditch. All the other railroad crossings will be at new locations, not replacements for existing rail crossings. There will be nine additional railway lines crossing the canal in the next 19 miles at the north end, with four other rail crossings on the other 74 miles of the canal.

b. US 12 is bridged across Burns Ditch, which will require a longer and higher replacement. There are two county roads and a state road across the lower Tippecanoe that will have to be replaced or closed. These are the only existing highway bridges that will be destroyed or made inadequate by the construction of the canal. There will be 13 additional bridges required for primary highways which will cross the canal. The canal will intersect 65 county roads which form an intricate network in northwestern Indiana. Some of these may have enough traffic to justify the construction of bridges; many of them, however, can be blocked off.

VI. CONCLUSIONS

29. Significant Findings.

a. This preliminary study indicates that the proposed Lake Michigan-Wabash River canal is most probably not feasible because of the limited water supply that is generally available from July to October and the lack of good water storage sites. More detailed cost analysis and evaluation of the potential water supply sources and storage sites and water requirements for the canal are needed to determine more conclusively the feasibility. Additional data are needed on the costs of the various phases of construction and operation to evaluate this project and to compare the route selected in this report with other potential alinements. The decisions in this study were made primarily on the basis of engineering judgment without the benefit of quantitative cost data. No figures were available to compare costs of various types of construction alternatives; for example, the cost of additional excavation could not be compared with the cost of construction and operation of additional locks. Further, the cost of the canal was not determined, therefore, it was not possible to make a comparison with benefits to the public to substantiate a recommendation for or against construction. However, the almost insoluble engineering problems associated with water supply probably argue against construction.

b. The following items are the most significant findings concerning the planning of the proposed canal from Lake Michigan to the Wabash River:

(1) The canal could be built without encountering major construction problems.

(2) A route can be selected which will by-pass all urban areas. Only near Lake Michigan will urban areas be very restrictive on the alinement selection.

(3) Although one route was selected over the other alinements considered, there are other routes which may be just as good. Since the surface is fairly level, the topography is not very restrictive in the route location.

(4) Water supply and storage are the greatest problems for the canal.

(5) Even in the spring and early summer when river flows are high, some water will have to be pumped considerable heights to the summit level of the canal. During the dry season in some years the streams may furnish very little, possibly none, of the canal requirements.

Since much of the water must be pumped anyway, a recirculating system would be an economical one to augment the water supply.

(6) Water from Lake Michigan could be pumped 100 feet to the summit level for use, but it must be returned to the lake in accordance with an international agreement between Canada and the states bordering the Great Lakes.

(7) Because of the rather level surface of northwestern Indiana, good reservoir sites are scarce. The dam forming Shafer Lake could be increased in height by 20 feet but this limited storage would still be beneath the summit level. Lake Freeman cannot be raised without flooding the town of Monticello.

(8) A dam on the Kankakee River could probably provide more than 500,000 acre feet of usable storage. Such a reservoir will flood over a hundred square miles of cultivated farmlands, but this appears to be the only reservoir site where sufficient water could be stored to ensure continuous operation of the canal through the extended periods of low flows.

(9) There are a number of lakes not too far from the proposed route, but they are rather small with little storage capacity, and the surface elevations are rigidly controlled by state law.

(10) The canal should be constructed to maintain a normal water depth of 11 feet, two more than the minimum, in order to provide water storage at the summit level for 1.4 days of operation.

(11) Considerable pumping of water to the summit level will be required, with lifts of 100 feet up from Lake Michigan and possibly 160 feet up from the Wabash River.

(12) Any proposed route will have to traverse about 20 miles of sandy soils, which will require special construction procedures to prevent seepage.

ANNEX A

STREAM FLOW DATA

1. Flow Data. USGS reports were the primary source of the stream flow information. The data were used to make reasonable computations on the amount of water available from various sources and to determine storage requirements to provide water during the periods of low flows.

2. Stream Flow Variation. For an estimate of the probable annual storage requirement for canal operation and the minimum annual supply potential of the sources, discharge records were reviewed to determine the period of the year when lowest flows were most likely to occur, the lowest of the average flows for this period in any one year, and the lowest annual average flows on record. Records published by the US Geological Survey through the 1960 water-year were used for this purpose. In addition to the gages listed in Figure A-1, two others were selected for review: one on the Kankakee at Shelby downstream from the canal crossing, the other at Ora on the Tippecanoe above

Monticello. In February, March, April, and May, the monthly mean flows on the larger rivers are generally higher than the mean for the period of record, lower than the mean for the period of record in each of the 5 months from July through November, and vary least from the mean for the period of record in December, January, and June. Generally, the months of lowest flows are the 4 months from July through October; however, low flow persisted through 5 months in some years to include either June or November. Records show that the average flow (expressed as a percentage of the mean flow for the station) during the respective 4-and 5-month low periods may be as low as 9 and 12 percent for the Wabash near Delphi (1941), where the period mean is 3,507 cubic feet/second, and as low as 37 and 39 percent for the Kankakee at Shelby (1925), where the mean is 1,500 cubic feet/second. Low flows on the Wabash and the Tippecanoe deviate more radically from the mean than do those of the Kankakee and the St. Joseph. For low average annual flows, the yearly averages were determined for selected years beginning with the month of December so as to place the assumed navigation season (April through November) and months of low flows at the end of the year. Several low annual average values for flow cast doubt on the adequacy of possible sources to provide the estimated canal requirement. The average annual flow for selected years of low flow, beginning with the month of December, ranged from 25 percent (873 c.f.s.) of the average for the period on the

PARTIAL STREAM GAGING RECORDS, INDIANA [a/]

	RIVER							
	WABASH	DEER CR.	TIPPECANOE	TIPPECANOE	KANKAKEE	YELLOW	IROQUOIS	ST. JOSEPH'S
GAGE LOCATION	Delphi	Delphi	Monticello	Delphi	Dunns Brg	Knox	Rensselaer	Elkhart
DRAINAGE AREA								
Square Miles	4,032	278	1,710	1,857	1,308	425	194	3,339
AVERAGE DISCHARGE								
c.f.s.	3,507	247	1,475	1,610	1,293	392	161	3,174
Years of Record	21	17	29	21	12	17	12	13
MAXIMUM DISCHARGE								
c.f.s.	89,800	14,400	16,800 e/	22,600	5,300	5,660	2,550	18,400
Date	18 May 43	10 Jun 58	13 Jun 58	10 Feb 59	22 Oct 54	15-16 Oct 54	10 Jun 58	5 Apr 50
MINIMUM DISCHARGE								
c.f.s.	97	5.6	103 e/	94 d/	290 b/	39 b/	4.9	564 e/
Date	25 Sep 41	27 Sep 54	27 Jul 34	1-2 Oct 41	14 Jan 54	11 Jan 57	24 Oct 56	1-2 Nov 56
HIGH DISCHARGE c/								
c.f.s.	7,315	510	3,145	3,224	1,685	661	299	5,264
Water Year	1950	1950	1950	1950	1952	1950	1950	1950
LOW DISCHARGE c/								
c.f.s.	842	63.7	514	548	829	225	71.7	2,093
Water Year	1941	1954	1941	1941	1953	1957	1954	1953
1954 WATER YEAR AVERAGE DISCHARGE								
c.f.s.	1,158	63.7	765	868	964	302	71.7	2,549

a/ USGS Water Supply Papers to 1960.
b/ Result of freezeup.
c/ Annual averages within period of record.
d/ Period of record to 1950.
e/ Daily average.

Figure A-1

Wabash near Delphi to 63 percent (808 c.f.s.) of the average for the period for the Kankakee at Dunns Bridge. For the year 1941, the combined annual average flow of the Tippecanoe at Monticello (545 c.f.s.) and the Kankakee at Shelby (992 c.f.s.) was only about 20 percent greater than the canal requirement, 1,250 cubic feet/second; the flow of the Wabash near Delphi for the same year was only 25 percent of the period mean. The average 1941 flow for the St. Joseph River was not available; however, records for another year (1953) show that below average flow on St. Joseph River can coincide with below average flows on rivers within the study area. The table in Figure A-2 presents flow values for the 1941 year, the lowest on record for the selected stations on the Tippecanoe and Wabash Rivers, and comparable values for the four main rivers for 1953, another year of low flows.

LOW FLOWS OF RIVERS

River	Gage Location	Mean Flow for Period of Record (c.f.s.)	Low Average Flow (% of Period Mean) 4-month	5-month	Average Flow (% of Period Mean) Annual a/
			(Year 1941)		
Tippecanoe	Monticello	1,475	17	21	37
Wabash	Near Delphi	3,507	9	12	25
			(Year 1953)		
Tippecanoe	Monticello	1,475	23	31	72
Wabash	Near Delphi	3,507	13	15	70
Kankakee	Dunns Bridge	1,293	34	39	63
St. Joseph	Elkhart	3,174	35	35	62

a/ December through November.

Figure A-2

3. <u>Comparison of Source Possibilities</u>. Possible sources outside the study area as well as inside were considered for supply of water to the canal; however, main consideration was given to sources within the study area. Outside the study area, only the St. Joseph River near Elkhart about 60 miles to the northeast was given much consideration as a possible source of supply, primarily because it appears to be the only source where any substantial amount of water might be obtained by gravity flow to the summit level of the canal. In addition to availability of supply, final determination of which sources to use depend on the relative costs of pumping water to the summit level, providing adequate water storage where required, and getting the water from the source to the canal.

a. The Tippecanoe River with an average discharge of 1,475 cubic feet per second at Monticello could be one of the main sources of water supply for the canal; however, it cannot be depended on every year. In one year its average flow was 550 cubic feet per second, and its average flow for a period of 4 months has been as low as 250 cubic feet per second. The gage at Ora has an elevation of 700 feet where the water could move by gravity flow to the summit level of the canal about 30 miles away. The average discharge at Ora is 821 cubic feet per second. The flow is much less at Ora than at Monticello and the storage possibilities are rather limited. It is evident that in years of average flow or better the Tippecanoe can provide a substantial amount of water for operation

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of the canal, but in occasional years of low flow, very little water could be diverted from the Tippecanoe.

b. From the standpoint of its average flow (1,293 c.f.s.) at Dunns Bridge, approximately 17 miles upstream from the proposed canal crossing, the Kankakee River appears to be one of the better sources of water supply. During one year, however, its average flow was approximately 830 cubic feet per second and its average for 4 months was slightly above 440 cubic feet per second. In the vicinity of the canal it flows approximately 40 feet below the elevation of the summit level and its elevation upstream from the canal is lower than the canal summit for a distance of approximately 60 miles. Pumped supplies, which would vary with seasonal flows, might be provided from the Kan-Kakee River by providing a weir and pool within the riverbed. Storage of flow for supply to the canal during a 4- or 5-month dry season would be a problem because of the difficulty of providing a good reservoir site.

c. The mean discharge of the Wabash River at the mouth of the Tippecanoe is 3,750 c.f.s., which is the sum of the measurements of 3,507 c.f.s. at the gage at Delphi about 6 miles upstream and the 250 c.f.s. discharge of Deer Creek, a left bank tributary of the Wabash between Delphi and the mouth of the Tippecanoe. The discharge of the Wabash is greater than that of the other rivers which are potential sources of water for the canal. It is 20 percent greater than the average discharges of the Tippecanoe and Kankakee together. Although the average discharge of the Wabash is greatest among the potential source streams, it is not considered to be a good source for several reasons. The average annual discharge of the Wabash at Delphi has been as low as 842 cubic feet per second or 25 percent of the mean discharge. Its average discharge for one 4-month period of low flow fell to 330 c.f.s., approximately 9 percent of the mean of all flows at Delphi. In addition to its extremes of low flows, the Wabash has other disadvantages as a source with respect to topography. Water supply from the Wabash River would probably require pumping from its level near the mouth of the Tippecanoe to the summit level of the canal, 160 feet above. The feasibility of supplying the canal by gravity from the Wabash is extremely doubtful. Elevations on the Wabash River above that of the canal summit are approximately 70 miles away, and the topography between the canal and the upper reaches of the Wabash consists of higher ridges with some low intervening valleys, making it very difficult to provide water flow by gravity across the region. Furthermore, this water will probably be needed to provide navigation facilities on the proposed Wabash-Lake Erie canal. If water were pumped from the Wabash at the mouth of the Tippecanoe to use in the Lake Michigan-Wabash canal, most of the water could be returned to the Wabash for reuse downstream.

d. The water in Lake Michigan is probably adequate to supply the canal throughout the navigation season with no detrimental effect on water surface level of the lake; however, use of water from the Great Lakes is restricted. An international agreement between Canada and the United States prevents the diversion of water from the Great Lakes or their tributaries unless it is returned or replaced to the Great Lakes. Water pumped from Lake Michigan could probably be used to supply the 310 c.f.s. required for operating the north locks and their leakage losses; this would be returned to the lake. Supply from Lake Michigan would require pumping through a height of 100 feet to the canal summit pool.

e. The average discharge of the St. Joseph River is 3,174 cubic feet per second at Elkhart, Indiana. The elevation of the gage datum is 700 feet at Elkhart, which is located outside the study area, approximately 60 miles northeast of the proposed canal crossing of the Kankakee River. Annual average discharges of the St. Joseph River at Elkhart show less variation than the annual average discharges of other possible sources. The lowest annual average discharge at Elkhart was 2,093 cubic feet per second, approximately 65 percent of the average discharge. The lowest average discharge at Elkhart during 4 months of low discharges was 1,100 cubic feet per second or 35 percent of the average discharge. The St. Joseph River was considered as a possible source primarily because of its substantial flows and its potential

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for gravity supply to the canal summit pool; however, aside from its considerable distance from the canal, its present use for hydroelectric power and its drainage to Lake Michigan detract from its potential as a source of supply for the canal. Information contained in the record of discharges indicates impoundments for hydroelectric power both above and below the Elkhart gage. The river drains to Lake Michigan and would be subject to the same restrictions referred to in connection with Lake Michigan, above, which would limit its use to the operating requirements and leakage loss for the north locks. The extent of use for any supply which might be available from the St. Joseph would be subject to an evaluation in relation to supply from Lake Michigan.

f. In the northern and eastern parts of the study area, the several lakes of glacial origin were discounted as feasible sources primarily because of probable low discharge potentials. The levels of lakes in Indiana are controlled by conservation laws which would restrict their use for purposes other than those now established.

g. The left (south) bank tributary of the Kankakee, enters the main river approximately 28 miles above the proposed canal crossing of the Kankakee. Called the Yellow River, its average discharge is 392 cubic feet per second at Knox, Indiana, which is located approximately 32 miles east of the canal alinement. The lowest annual average discharge for the Yellow River has been 225 cubic feet per second. Low flows on the Yellow River occur approximately 1 month later than on the main rivers of the area. Its average flow for a 4-month period of low flows during the navigation season was approximately 100 cubic feet per second. An elevation of 680 feet for the gage datum at Knox indicates a possibility for a limited supply of water by gravity from some location above Knox.

h. The Iroquois River, a tributary of the Kankakee is a relatively minor source with a low potential for water supply for the canal. Its importance is related to the location of its headwaters which constitute a large part of the drainage area on both sides of the canal summit pool. Near Rensselaer, about a mile west of the canal alinement, the gage elevation is 642 feet. The average discharge from this drainage system, measured at Rensselaer, is 161 cubic feet per second. Its lowest annual average discharge was approximately 70 cubic feet per second. Its average discharge for the low 4 months of the navigation season has been less than 15 cubic feet per second.

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ANNEX B

OVERLAYS, ELEVATIONS AND STRIP MAP

NOTE: These are reduced copies of the overlays from Volume II.

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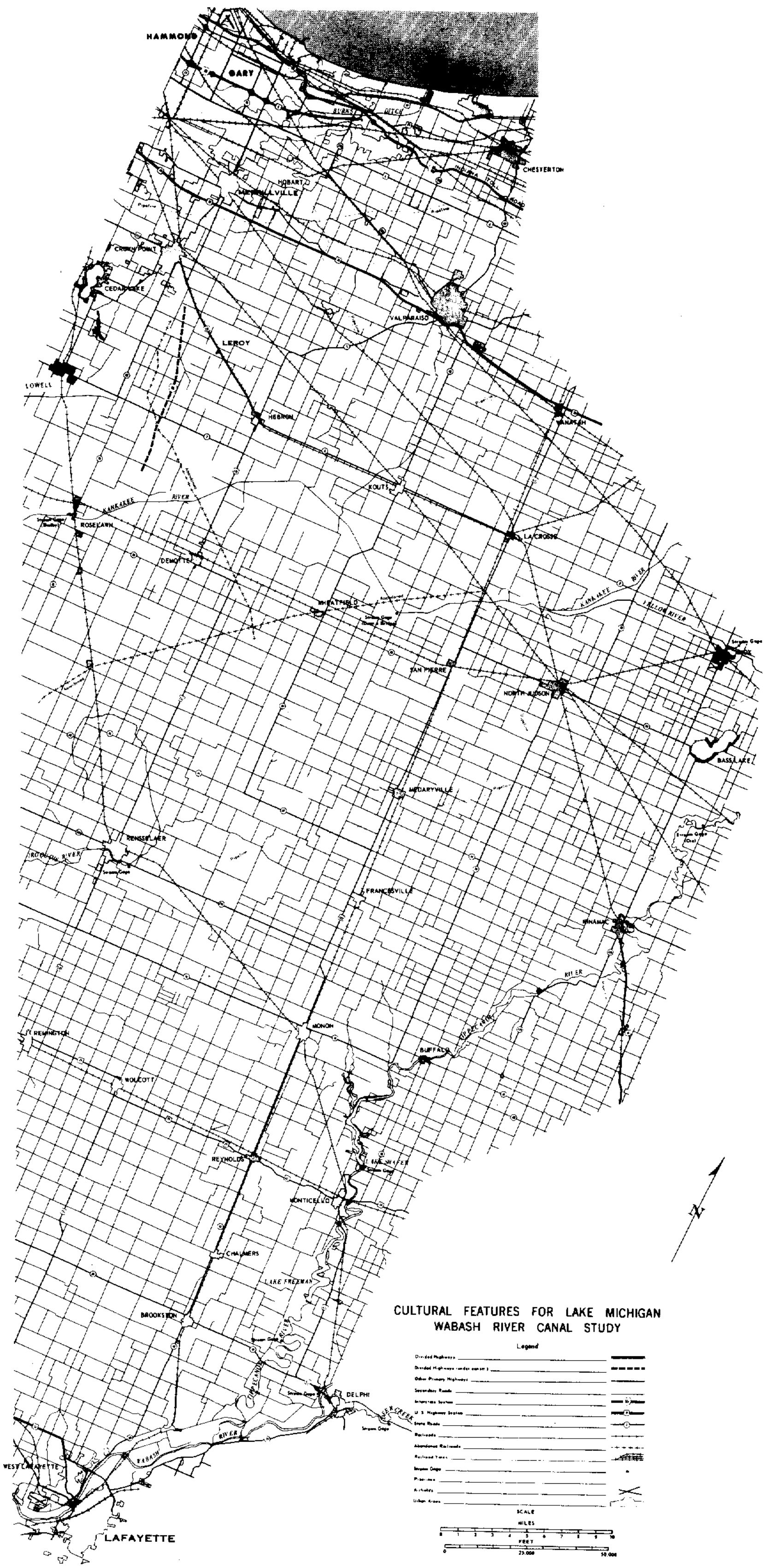
HAMMOND
GARY
CHESTERTON
HOBART
MERRILLVILLE
CROWN POINT
CEDAR LAKE
VALPARAISO
LEROY
LOWELL
HEBRON
WANATAH
KOUTS
ROSELAWN
KANKAKEE RIVER
LA CROSSE
DEMOTTE
WHEATFIELD
YELLOW RIVER
SAN PIERRE
NORTH JUDSON
BASS LAKE
MEDARYVILLE
RENSSELAER
FRANCESVILLE
WINAMAC
MONON
REMINGTON
BUFFALO
WOLCOTT
REYNOLDS
MONTICELLO
CHALMERS
LAKE FREEMAN
BROOKSTON
DELPHI
WEST LAFAYETTE
LAFAYETTE
CULTURAL FEATURES FOR LAKE MICHIGAN
WABASH RIVER CANAL STUDY
Legend
Divided Highways
Divided Highways (under constr.)
Other Primary Highways
Secondary Roads
Interstate System
U. S. Highway System
State Roads
Railroads
Abandoned Railroads
Railroad Yards
Stream Gage
Airfields
Urban Areas
SCALE
MILES
0 1 2 3 4 5 6 7 8 9 10
FEET
0 25,000 50,000
N

Figure B-1

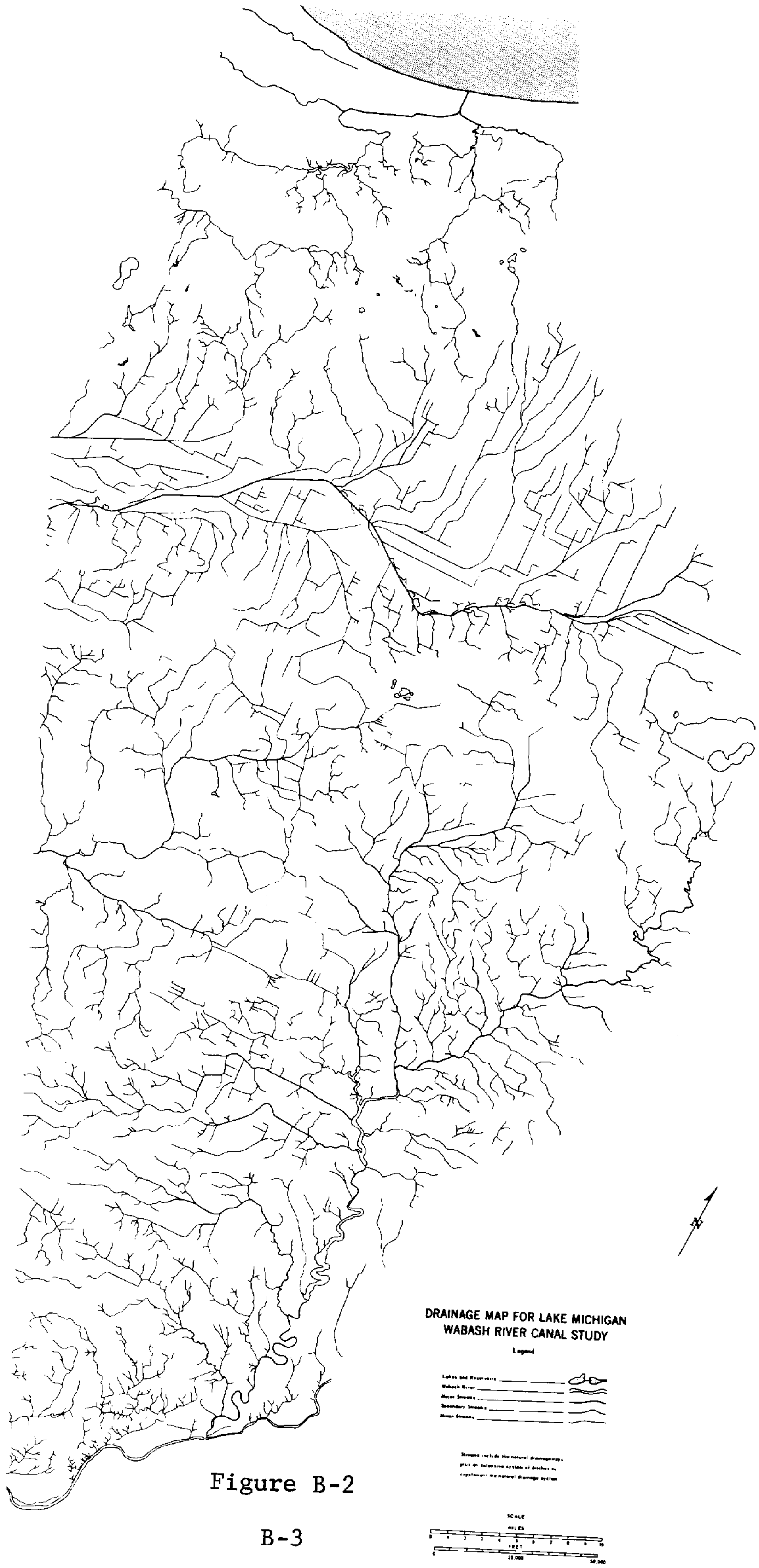

Figure B-2

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LAKE MICHIGAN
LAND USE MAP FOR LAKE MICHIGAN
WABASH RIVER CANAL STUDY
Legend
V VEGETATION
U URBAN
Other Urban
TRANSPORTATION
SCALE
MILES
0 1 2 3 4 5 6 7 8 9 10
FEET
0 25,000 50,000

Figure B-3

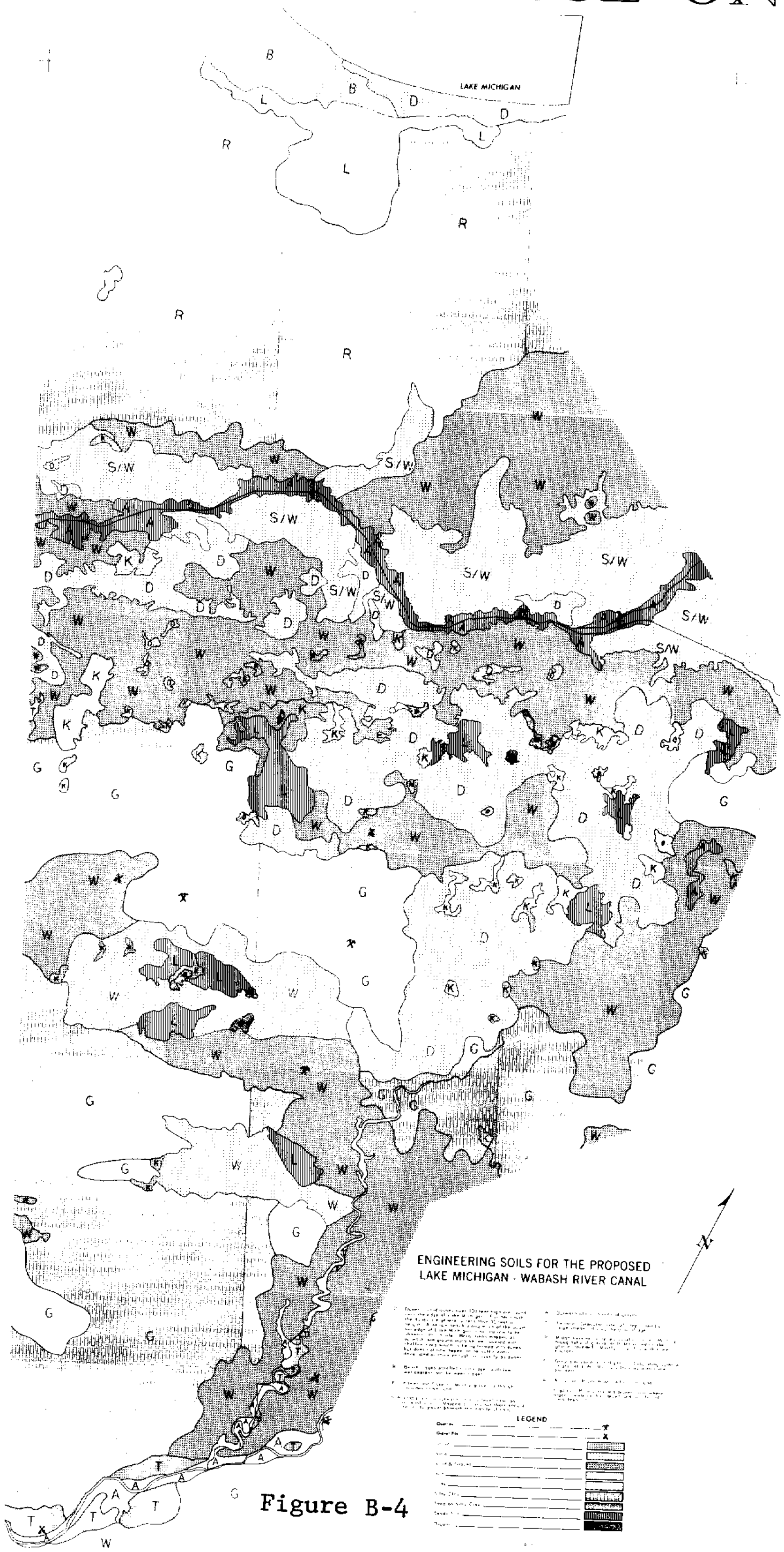
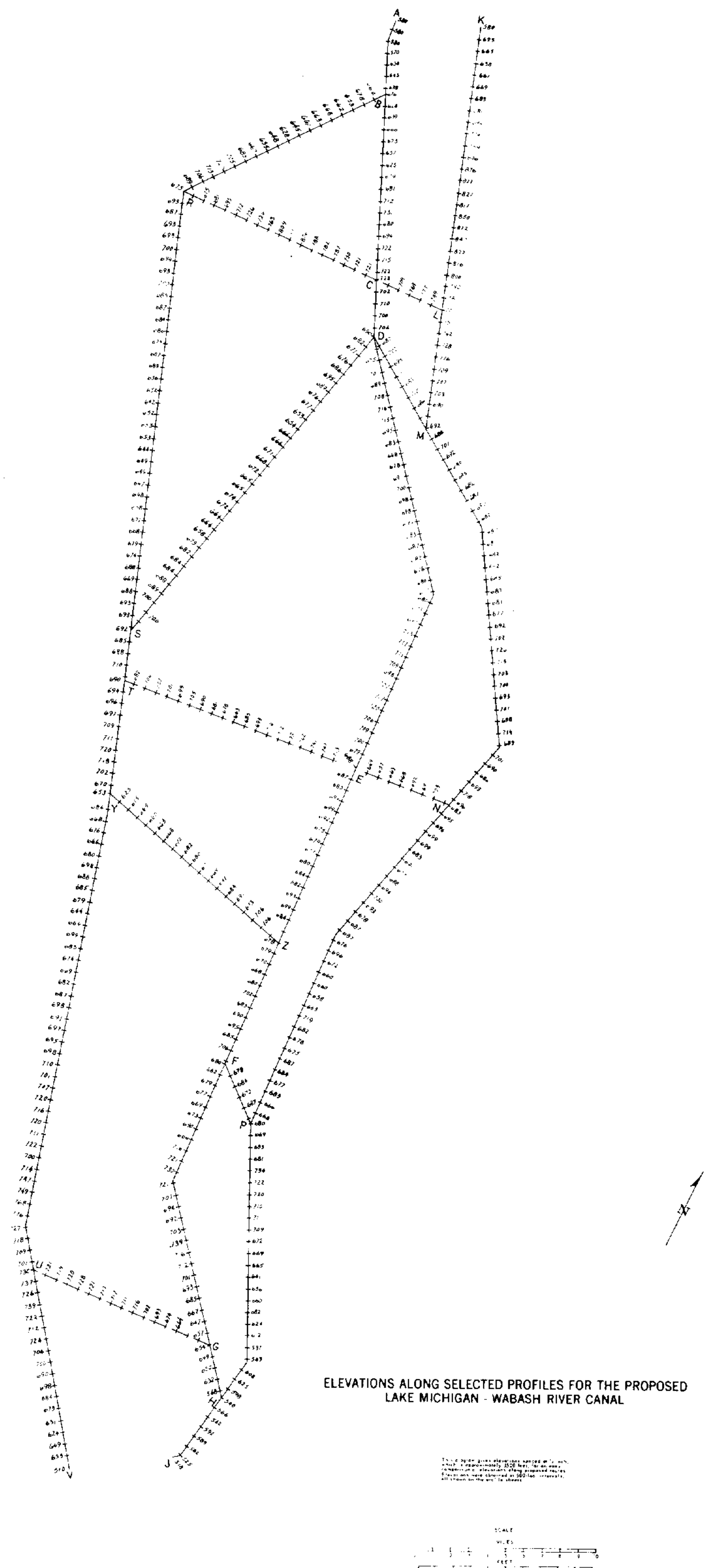

LAKE MICHIGAN
ENGINEERING SOILS FOR THE PROPOSED
LAKE MICHIGAN - WABASH RIVER CANAL
LEGEND

Figure B-4



ELEVATIONS ALONG SELECTED PROFILES FOR THE PROPOSED
LAKE MICHIGAN - WABASH RIVER CANAL

Figure B-5

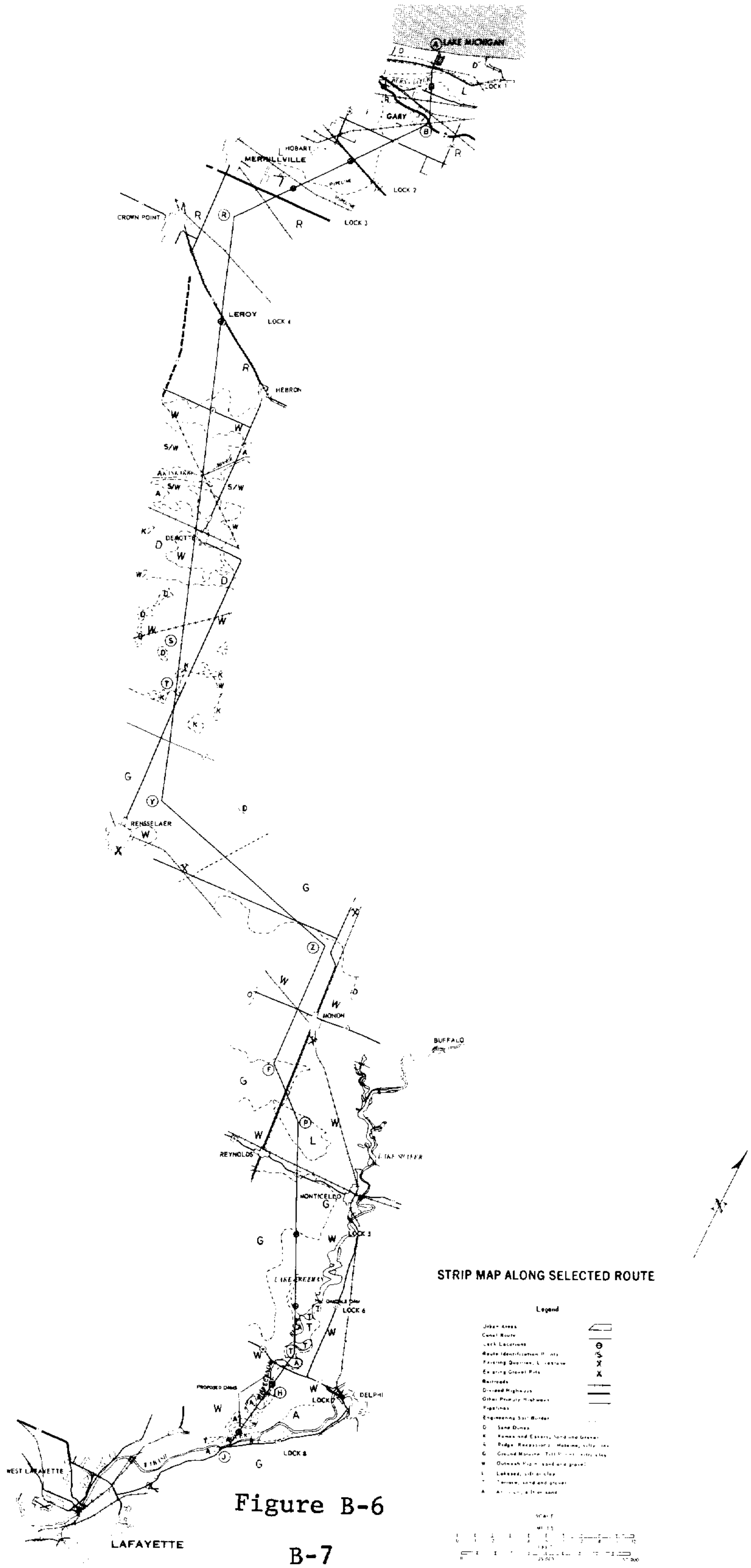

LAKE MICHIGAN
GARY
HOBART
MERRILLVILLE
LOCK 1
LOCK 2
LOCK 3
CROWN POINT
LEROY
LOCK 4
HEBRON
RENSSELAER
MONON
BUFFALO
REYNOLDS
MONTICELLO
LOCK 5
LOCK 6
DELPHI
LOCK 8
WEST LAFAYETTE
LAFAYETTE
STRIP MAP ALONG SELECTED ROUTE
Legend

Figure B-6

ANNEX C

WATER COMPUTATIONS

1. Lock Requirements. Flow requirements for lock operation were computed for each series of locks on the basis of 20 fillings of the controlling lock chamber each day. Horizontal dimensions of lock chambers being the same for all locks, the highest lock lift determined the controlling lock in the series. For the north locks, with a controlling lift of 25 feet, the flow requirement was computed to be 292 cu ft/second. The south locks would require a flow of 583 c.f.s. for a controlling lift of 50 feet. A sample computation for the flow "Q" required for lock operation follows:

$$Q = \frac{\text{Volume of lock chamber x fillings/day}}{\text{Seconds/day}}$$

Example for a controlling lock lift of 30 feet:

$$Q = \frac{(84 \times 600 \times 30)(20)}{86{,}400} = 350 \text{ c.f.s.}$$

2. Canal Losses. Only the greatest sources of loss from the canal were considered in the flow estimate presented in this study. The greatest water losses would be those due to leakage through the locks, evaporation and seepage from the canal, and evaporation from pools formed above dams. Other losses, such as those attributable to leakage and overflow at appurtenances, would be relatively minor and were thus neglected for this estimate. The leakage through locks, although dependent upon lock height, was assumed to be 20 c.f.s. at each lock, regardless of its height. The leakage loss through a series of locks was regarded as being equal to that for one lock in that the leakage from the summit pool was assumed to flow equally through all locks in the series. Thus, the loss due to lock leakage would be 20 c.f.s. for the series of locks on each end of the canal. Leakage around the two proposed dams on the Tippecanoe River was assumed to be incorporated with the base flow of the river and was not accounted for separately. On the basis of factors on record for several existing canals, a value of 3.0 c.f.s. per mile was assumed to be adequate for computing the combined losses due to evaporation and seepage from the canal. The loss due to evaporation and seepage, for a total canal distance of 90 miles, was computed to be 270 cu ft/second. For the evaporation rate from pools formed above dams, a value of 6 inches/month was considered adequate for the dry months of the navigation period. There are three pools of this type, two on the Tippecanoe and one on the Wabash with a total

surface area of approximately 8,240 acres. The surface areas of the Tippecanoe pools in downstream order were estimated to be 4,050 acres and 1,050 acres. The surface area of the Wabash pool, at the mouth of the Tippecanoe, was estimated to be 3,140 acres. Seepage from pools above dams was assumed to be a minor loss, as impoundments would be mainly within the banks of streams. Based on the above values for pool areas and rate of evaporation, a flow of 70 c.f.s. would be required to replenish the evaporation loss from pool surfaces during the period of maximum evaporation.

3. Reservoir Losses. Because of reservoir losses caused by evaporation and seepage, the total flow requirement will increase with the storage reservoir capacity provided to supply the canal during periods of low flow. Only the evaporation loss was considered significant in estimating the reservoir storage loss. The seepage loss from storage reservoirs was assumed to be negligible. The average annual evaporation loss from lake surfaces in Indiana can be assumed to be approximately equal to the precipitation which might average about 36 inches per year. About 75 percent of the evaporation from reservoirs, in general, takes place from April through September with approximately 20 percent of the total occurring during the maximum month. On the basis of the above values, considering that the lowest flows in the project area can extend over at least a 4-month period, an average evaporation rate of 6 inches/month was assumed for the 4 months during

which the maximum evaporation rates and demand for supply from storage would occur. The depth of effective storage and the average surface area for reservoirs was assumed to be 15 feet and three-fourths of the full pool surface area, respectively.

4. Storage Requirements. Storage reservoir requirements for various years may range from zero to the amount of storage needed to supply the total canal requirement during several months of low flows. A maximum storage requirement for a year of extremely low discharges in the navigation season was assumed to be the storage needed to provide the total canal requirement (1,250 c.f.s.) for a period of 4 months. Considering also the evaporation loss from reservoirs to store this 4-month requirement, the necessary storage volume would be 330,000 acre-feet. For the minimum storage requirement, a condition was assumed wherein water used for canal operation and leakage through locks could be conserved and reused; thus, the storage needed would equal to the sum of evaporation and seepage losses in the canal system (340 c.f.s.). Again considering the reservoir evaporation loss, the reservoir storage needed to supply 340 c.f.s. for a period of 4 months would be 90,000 acre-feet. A third condition was considered in addition to maximum and minimum requirements, where reservoir supply would be provided to satisfy only the seepage and evaporation losses and the requirement for operating the south locks (940 c.f.s.). The north locks would be supplied with water from Lake Michigan. The reservoir capacity, considering the reservoir

evaporation loss, for 940 c.f.s. over a period of 4 months would be 250,000 acre-feet. However, in an extreme year when the period of very low flows might extend to about 6 months, the storage requirements could be 50 percent greater than those mentioned above.

ANNEX D

WATER CONSERVATION

1. Thrift Locks. The water requirement for operating the locks could be reduced through the use of thrift locks. Thrift locks, probably the most usual device employed for this purpose in Europe, consist of one or more shallow basins at different levels constructed adjacent to the lock into which part of the water from the full lock chamber is emptied and stored. The water stored in the thrift basins is reused in the same lock during the next refilling of the lock. The amount of water saved each time the lock chamber is emptied depends on the number of thrift basin levels and the ratio of the breadth of the lock chamber to that of the thrift basin at any one level. (The breadth of the thrift basin would be the sum of the basin widths at the same level on both sides of the lock.) Two thrift basins, each having the same total breadth as the lock chamber and the proper depths could reduce the water requirement for the lock by one-half; six thrift basins, each with the same total breadth as the lock chamber would reduce the water requirement for the lock by three-fourths. Three-fourths of the lock chamber volume

could be saved by using four or five thrift basins having breadths 3 and 1.5 times that of the lock chamber, respectively. A water requirement of 25 percent of that required for ordinary locks is a reasonable value to assume to be possible with thrift locks; this value may be realized for four, five, and six thrift locks having total breadths of 3, 1.5, and 1 times that of the lock chamber, respectively. If the water requirement for lockages were reduced by 75 percent through the use of thrift locks, the total water requirement for the canal would be reduced from 1,250 cubic feet per second to 600 cubic feet per second. Because of variations of design that might be assumed for thrift locks and unknown factors that could limit the size, conventional locks were assumed for the project design. All estimates herein for water requirements and supply were based on conventional locks.

2. Supply by Recycling. The recycling of water in the canal system, by pumping water back to higher pools after it has been used in the locks, might keep the canal in operation during periods when adequate water is not available from potential sources which have been developed. One system for maximum recycling of water within the system could be effected by means of pumping at three locations on the waterway as follows: pumping to the summit pool (elevation 680 ft) from Lake Michigan (elevation 580 ft) would supply water used in the operation of the series of four 25-foot locks at the north end of the canal; pumping to the summit pool from the pool that would be formed by the dam for lock number seven

(elevation 580 ft) would recycle outflows from the two 50-foot locks at the south end of the canal; pumping to the Tippecanoe pool for lock number seven from the pool to be formed on the Wabash River (elevation 520 ft) at the mouth of the Tippecanoe would supply water for the two 30-foot locks on the Tippecanoe. Fluctuations in pool surface levels caused by storage of the daily quantities required for lock operation and leakage (less than 1 foot on the Tippecanoe and Wabash pools and less than 2 feet for the summit pool) were assumed to be within tolerable limits. In a system for recycling the outflows from the waterway locks, water must still be supplied to the canal system from available source flows or reservoir storage to replace losses due to evaporation and seepage. It should also be considered that a system of recycling canal outflows over a period of weeks or months could cause a problem due to a buildup of pollutional loads. The dilutional effect of the Tippecanoe and Wabash natural flows through the navigation pools may be insufficient to offset pollutants from barge traffic and populated places served by the Tippecanoe and Wabash Rivers, especially during periods of low flow.

ANNEX E

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