Lake Lemon Conservancy District

April 19, 2017

Sediment Management Alternatives Analysis

Report prepared for the Lake Lemon Conservancy District -Unionville, IN

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KCI TECHNOLOGIES

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1.0 Purpose and Need

Lake Lemon was developed in 1952 as a manmade impoundment. As is the case with any of these artificially made systems, the lake has a limited operational life (100-125 years) for its intended purposes. Lake Lemon is at a threshold in that life cycle as functions continue to be compromised within the lake and watershed surrounding it. As such, more intense management of the system is being planned to adaptively manage the stressors being placed on the lake both internally and externally to extend the useful operational life of the asset. The purpose of this analysis is to evaluate the impacts of sediment on the system and evaluate alternatives to manage stressors to achieve the objectives of the Conservancy District.

2.0 Supporting Information and Data Sources

The development of this report relied upon data and reports prepared by others as well as communications with lake management staff and board members to understand in-situ conditions and on-going management actions being utilized. This information provided the basis of assumptions utilized to conduct this analysis. The specific sources utilized are as follows;

- Revised District Plan, Lake Lemon Conservancy District, December 1998
- Lake Lemon Diagnostic Feasibility Study, Indiana University, April 1986
- Bathometric Survey, Remetrix LLC, October 2004
- Soft-Sediment Depths, Bathymetry, and Volumetric Updates of Lake Lemon, IN. Final Report, Remetrix December 2014
- Lake Lemon Conservancy District, Freeholder Survey Report, Indiana University, July 2015
- Lease Agreement, Lake Lemon Conservancy District and City of Bloomington, November 1995
- Conversation with Adam Casey, Lake Manager December 8, 2016
- Conversation with Frank Van Overmeiren, Study Sponsor, December 9, 2016

3.0 Objectives

The two primary objectives of the Conservancy District, as established in the 1998 District Plan, are focused on Water Quality and Recreational Use of Lake. These objectives and their attributes are defined as follows:

Water Quality – Maintain the water quality of the lake in a manner that it can be used as a water supply reservoir should the need arise.

- Meet minimum drinking water standards
- No swimming restrictions
- No Algal blooms
- Improved TSI scores

Recreational Use of Lake – Maintain the lake in a manner that allows continued use of the lake for Swimming, Boating and Fishing.

- Maintain swimmable area of lake
- Maintain area of lake available to boating
- Maintain area of lake available for fishing and increase quality of available resource

These objectives are consistent with the conditions of the Lease with the City of Bloomington and are influenced by both internal and external stressors surrounding the lake. External stressors include watershed conditions, which will need to be addressed by partnerships with watershed stakeholders, and internal stressors, which are influenced by lake management activities, and adjacent land uses. **For the purposes of this analysis these objectives will be evaluated as they relate to sediment management, the underlying threat compromising the integrity of the lake system.**

4.0 Existing Conditions

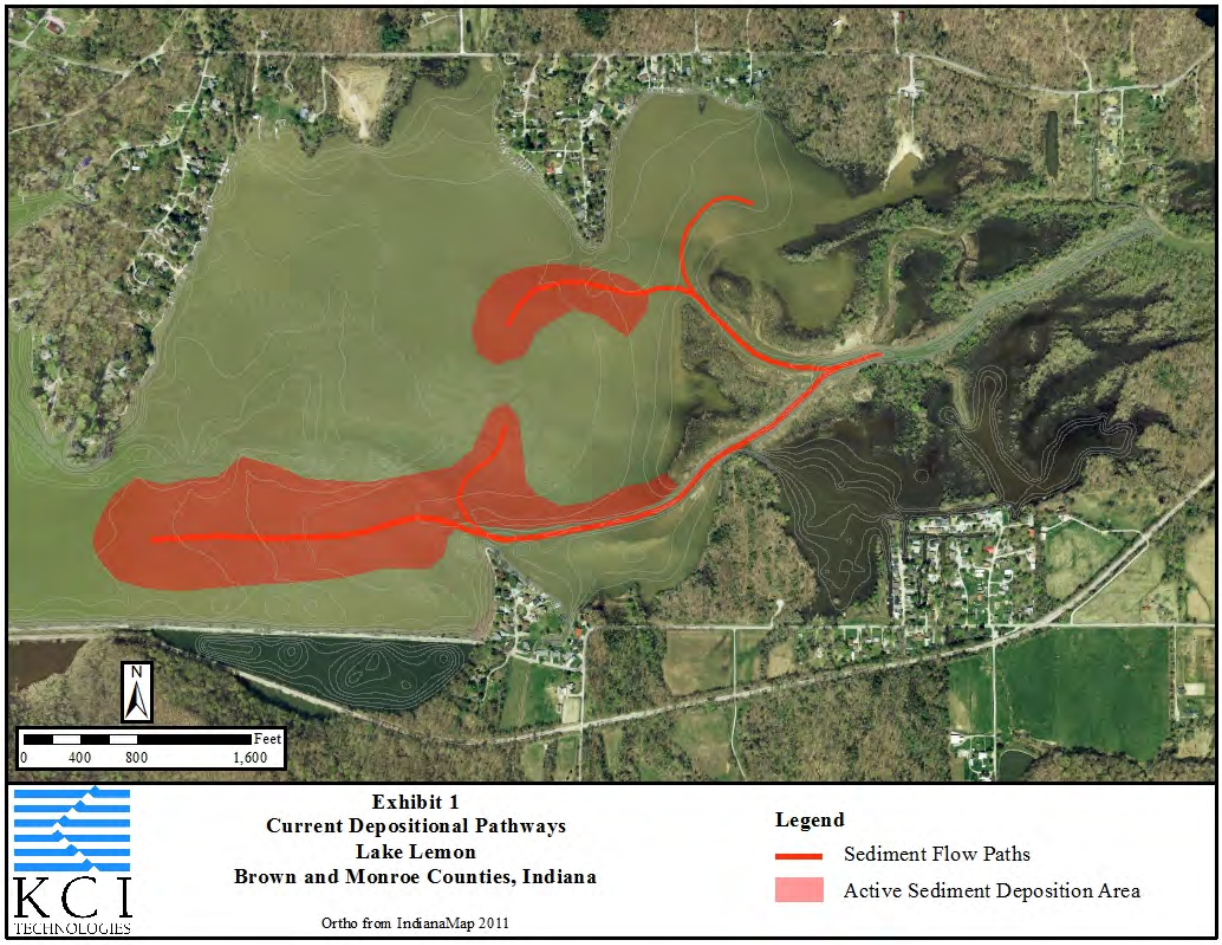
Lake Lemon was originally developed as a regional water supply reservoir for the City of Bloomington. By the early 1990's, the development of other water supplies made the management of the lake cost prohibitive and the city was considering decommissioning the lake. As the lake had already become a significant recreational asset, and buoyed property values in the area, a local group sought to assume the operation and maintenance of the lake. In 1995, the Lake Lemon Conservancy District was formed to assume the responsibility of maintenance on the lake.

Of primary consideration for this study is the management of sedimentation in the lake. Currently a large delta has and continues to form in the eastern end of the lake. This delta is composed of approximately 220,000 cubic yards of material, and exists both above and below the base water level. The delta has formed in a very classic fluvial geomorphic fashion, depositing material through the path of least resistance to water flow, until that area becomes more resistant, then transitioning to an alternative pathway until the same condition occurs (Exhibit 1). This process creates what is known as a bird's foot delta, named for the shape of the distribution channels, which often resemble a bird's foot. The material in the delta is likely coarser sediments pulled from suspension as soon as the contributing drainage reaches the backwater of the lake. Finer materials settle further into the lake and their presence is evident in the prior bathometric studies conducted. The relative distribution of the sediment deposition by size cannot be determined from the information currently available.

The following conditions were deduced from the ancillary studies conducted on the lake since 1988 and through review of historic photographs to develop alternatives for consideration.

- Sediment is being deposited into the lake at a rate between 15,000 and 40,000 cubic yards per year.
- Lake volume (depth) has decreased by 6.2% since the lake was first studied in 1988 as a result of sediment input.
- Sediment is being disproportionately deposited into the East end of the lake.
- Sediment deposition has direct and in-direct impacts on water quality through SAV management, algae development, and nutrient loading.
- The current sediment removal program is largely combating shoreline erosion deposits and not tributary loading.

Exhibit 1 – Current Depositional Pathways



5.0 Key Issues

The following issues have direct impact on the recreational use and water quality within the lake and have direct and indirect relationships with sediment loading in the system. Some of the resolutions for these issues are presented for clarity, but are beyond the scope of this analysis.

Issue: Sedimentation

Lake Lemon is used extensively for recreation. These activities (boating, fishing, swimming) are adversely affected by sediment deposition in the lake. In addition, sediment deposition has direct and in-direct impacts on water quality through Submerged Aquatic Vegetation (SAV) growth, algae development, and nutrient loading compromising the overall health of the system. These impacts disproportionally impact the eastern end of the lake due to the inflow from Bean Blossom Creek.

Potential Resolutions:

Initiate dredging program to remove/manage sediment
Reduce sediment input into the system

Issue: Submerged Aquatic Vegetation (SAV) Growth

SAV has become a problem in some sections of the lake. This trend has been exasperated by a combination of decreasing water depths, due to sedimentation, and increased nutrient loading into the system. As SAV has both positive and negative impacts on the desired recreational use of the lake, the balance within the system needs to be determined.

Potential Resolutions:

Establish region specific management program for SAV
Modify physical conditions of lake to limit aerial extent of SAV development

Issue: Water Quality

The overall water quality of the lake has remained relatively consistent for the past 17 years but can vary widely based on watershed inputs. The general condition of the lake is eutrophic, which in combination with sedimentation, can impact SAV growth rates and extents, algal growth, clarity, oxygen levels, fish habitat, and odor. All of these degradation issues could also jeopardize the future of Lake Lemon as a potential reservoir.

Potential Resolutions:

Reduce nutrient loading from contributing watershed
Reduce nutrient loading from riparian zone of lake
Establish management actions to process/reduce internal and external loading
Establish and maintain nutrient management budget

6.0 Alternatives Development and Evaluation

The primary objective of this study is to develop alternatives to manage the sediment inputs of the lake. As any strategy to manage sediment in the system will have direct and indirect impacts on achieving the primary objectives of the Conservancy District's management of the lake, the developed alternatives also qualitatively consider those pre-established objectives within the 1998 District Plan.

An evaluation of the current conditions and key issues were used to create alternatives that address the objectives of the District as can be achieved through sediment management. Four alternatives were developed: 1.) Current Actions, 2.) Managed Delta - In Place Management, 3.) Dredging/Removal, 4.) Managed Delta - Hybrid Removal/Management. These alternatives were then evaluated for their ability to fully or partially meet established objectives and address the key issues that may impact the implementation of the program.

These Alternatives were based on the following assumptions;

- Approximately 15,000 to 40,000 cubic yards of sediment is being delivered to the lake from the watershed each year.
- Sediment deposition in the lake adversely impacts recreational uses of the lake.
- The lake is managed and evaluated as a single system without regard to the spatial distribution of the assets on the lake.

Based on the aforementioned assumptions each alternative was evaluated to assess its ability to meet the objectives of the Conservancy District and resolve specific issues identified in relation to sediment management.

Table 1 – Objectives and Issue Summary

Objective	Alternative 1 Current Actions	Alternative 2 In Place Management	Alternative 3 Large Scale Dredging/Removal	Alternative 4 Hybrid Removal/Management
Water Quality				
Drinking Water	F	F	P	F
Swimmable	F	P	P	P
TSI scores	F	P	P	P
Recreational Use				
Boating Area	P	P	F	P
Swimming Area	P	P	F	P
Fishing Area	F	F	X	F

F – Fully Supports P- Partially Supports X - None Supporting

Issue				
Sedimentation	Maintained	Maintained	Reduced	Reduced
SAV Growth	Increased	Maintained	Reduced	Maintained
Water Quality	Improved	Maintained	Decreased	Maintained
Boating Area	Reduced	Maintained	Increased	Maintained
Swimming Area	Reduced	Reduced	Increased	Maintained
Fishing Area	Increased	Increased	Reduced	Increased

6.1 Alternative 1 – Current Actions

This alternative considers the effects of taking no action or minimal action in regard to sediment management. Currently a large delta has formed in the eastern end of the lake, this delta will continue to grow over time adding 15,000 to 40,000 cubic yards of sediment per year. The delta will deposit both above and below the normal water surface elevations. Over time this delta will vegetate and become permanent fast land. Using the existing water depths of the lake, the rate of sediment input into the system, and fluvial geomorphic process models, an estimate of the future extent of this feature was developed. The decrease in water depth and nutrient loading from the watershed will increase the area available for colonization by SAV. Maintenance dredging to provide ingress and egress around the lake will continue at the rate of 10,000 – 12,000 cubic yards per year.

Objectives Attainment:

Water Quality

Water quality will likely improve as nutrient laden sediments will be placed in deep sequestration within the delta and the increase in SAV will reach an equilibrium with the available sediments.

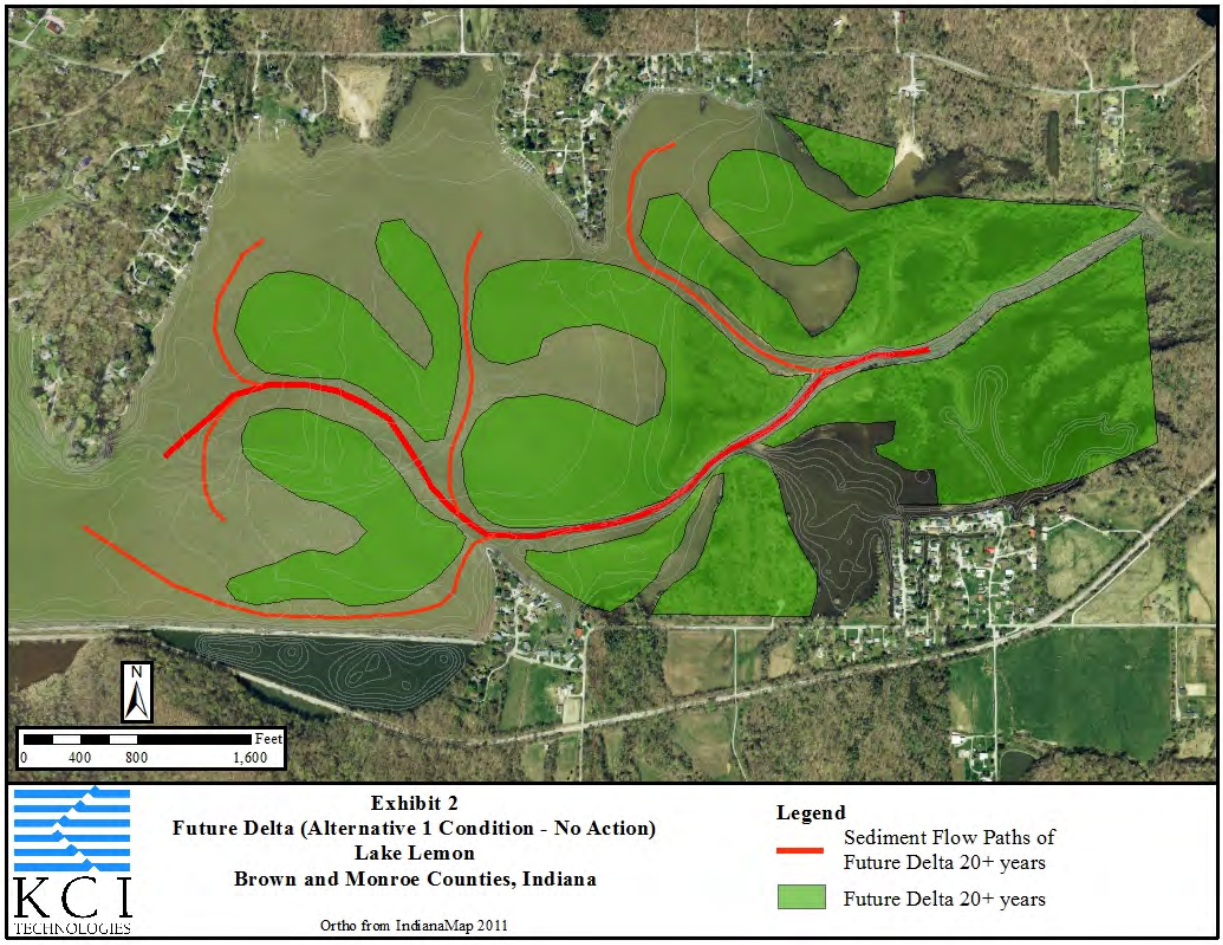
Recreational Use

- **Swimming** – the increase in water quality will increase water clarity and promote the development of SAV both in the area of the delta and in other near shore areas of the lake, decreasing the opportunities for swimming
- **Boating** – Significant areas of the eastern lake will be shoaled reducing the net area in the lake available for boating
- **Fishing** – The increased area of water in the 0 to 5’ depth and increased volume of SAV will increase the net productivity for fish in the lake and overall fishable area.

Key Issues Resolution

- **Sedimentation** – This alternative provides no active management of the sediment inputs into the system. It allows natural fluvial geomorphic processes to take place. As such, it does not address volume or manner in which the sediment is influencing the lake.
- **SAV Growth** – This alternative would likely increase the growth of SAV in the lake. The growth would likely reach an equilibrium with available nutrients and other water quality parameters which dictate type and extent of SAV beds.
- **Water Quality** – With the growth of in-lake vegetation and deep sequestration of nutrients in sediments, water quality would improve as the system reached a functional equilibrium.
- **Recreational Capacity** – The recreational capacity of the lake would be significantly shifted. Areas available to swimming and boating would decrease but the quality and area available for fishing would increase.

Exhibit 2 – Future Delta (Alternative 1 Condition)



6.2 Alternative 2 - Managed Delta - In place Management

This alternative considers managing and controlling the inflow of sediment into the system by manipulating the fluvial geomorphic process to create an engineered delta. This will allow the controlled formation of the delta as "in place" storage of the material. This effort will require the surrender of current open water areas of the lake, and abandonment of some ingress/egress routes in the lake. To accomplish this alternative, flow control structures would need to be established in the flow path of Bean Blossom Creek to direct sediment laden flows to areas where they can settle and be contained. In addition some naturalized containment zones would need to be established using onsite native materials, vegetation or structure, to limit the growth extents of the delta. Areas outside of the managed delta will be dredged and used to create the containment zones, and inhibit SAV growth.

Objectives Attainment:

Water Quality

Water quality will likely improve as nutrient laden sediments will be placed in deep sequestration within the delta and SAV growth within the boundaries of the managed delta will aid in processing nutrients and precipitation of sediments in the system.

Recreational Use

- **Swimming** – the increase in water quality will increase water clarity and promote the development of SAV both in the area of the delta and in other near shore areas of the lake, however localized dredging will be used to control the extents of SAV beds maintaining the opportunities for swimming
- **Boating** – A large area within the eastern end of the lake will be established as the delta management zone and reduce the net area in the lake available for boating.
- **Fishing** – The increased area of water in the 0 to 5' depth and increased volume of SAV will increase the net productivity for fish in the lake and overall fishable area.

Key Issues Resolution

- **Sedimentation** – This alternative provides an adaptive management approach to control of sediment inputs into the system. It manipulates natural fluvial geomorphic processes to create a controlled growth of a delta. It does not address the volume of sediment entering the lake but does manage the manner in which the sediment is influencing the lake.
- **SAV Growth** – This alternative would likely increase the growth of SAV in the lake, however that growth would be focused in delta management zone.
- **Water Quality** – With the growth of in lake vegetation and deep sequestration of nutrients in sediments, water quality would improve slightly.
- **Recreational Capacity** – The recreational capacity of the lake would be improved for swimming and fishing, and decrease slightly for boating as open water is sacrificed for a managed delta.

6.3 Alternative 3 - Dredging/Removal

This alternative considers removal of the sediment from the lake at a much larger scale than current efforts. In order for this alternative to be effective, an average of 25,000 cubic yards of material would need to be removed from the lake annually to keep up with contributions from the watershed. In addition, removal of 220,000 cubic yards would be necessary to address current delta deposits. This alternative would require significant increases in both equipment and dredged material disposal locations to be effective.

Objectives Attainment:

Water Quality

Water quality would likely be impacted by the removal of most sediments in the lake. Removal of material in these volumes would require a continuous effort and would likely result in suspending of fine sediments and associated nutrients in the water column. This would also remove significant amounts of SAV and the associated nutrient processing functions they provide.

Recreational Use

- **Swimming** – The decrease in area available for SAV colonization would improve swimming access, but the decrease in water quality would offset the quality of that activity.
- **Boating** – Removal of accumulated and incoming sediments would significantly increase the area available for boating.
- **Fishing** – The net decrease in SAV and increase in deeper water areas, combined with a net decrease of water quality would reduce the quantity and quality of fishing in the lake.

Key Issues Resolution

- **Sedimentation** – This alternative fully resolves the issue of sedimentation of the lake.
- **SAV Growth** – This alternative would fully resolve SAV growth issues within the lake.
- **Water Quality** – This alternative would likely create a long term trend of water quality degradation within the lake without some physical or biological means to cycle nutrients within the system.
- **Recreational Capacity** – The recreational capacity of the lake would be significantly shifted towards boating. While areas available to swimming would increase, the water quality of the system may affect the condition of human contact allowances within the system. Fishing would be reduced substantially in both quality and quantity as critical habitat is lost.

6.4 Alternative 4 - Managed Delta - Hybrid removal/management

This alternative considers managing and controlling the inflow of sediment into the system by manipulating the fluvial geomorphic process to create an engineered delta. This will allow the controlled formation of the delta as "in place" storage of the material. This effort will require the surrender of current open water areas of the lake, and abandonment of some ingress/egress routes in the lake. To accomplish this alternative, flow control structures would need to be established in the flow path of Bean Blossom Creek to direct sediment laden flows to areas where they can settle and be contained. In addition some naturalized containment zones would need to be established using on site native materials, vegetation or structure, to limit the growth extents of the delta. Areas outside of the managed delta will be dredged and used to create the containment zones, and inhibit SAV growth. This alternative would also include a separate element to remove material deposited into the delta to an offsite location to increase the life span of the system. The primary variance between this and Alternative 2 are cost and life span. All other objective and issue resolution items remain constant.

Objectives Attainment:

Water Quality

Water quality will likely improve as nutrient laden sediments will be placed in deep sequestration within the delta and SAV growth within the boundaries of the managed delta will aid in processing nutrients and precipitation of sediments in the system.

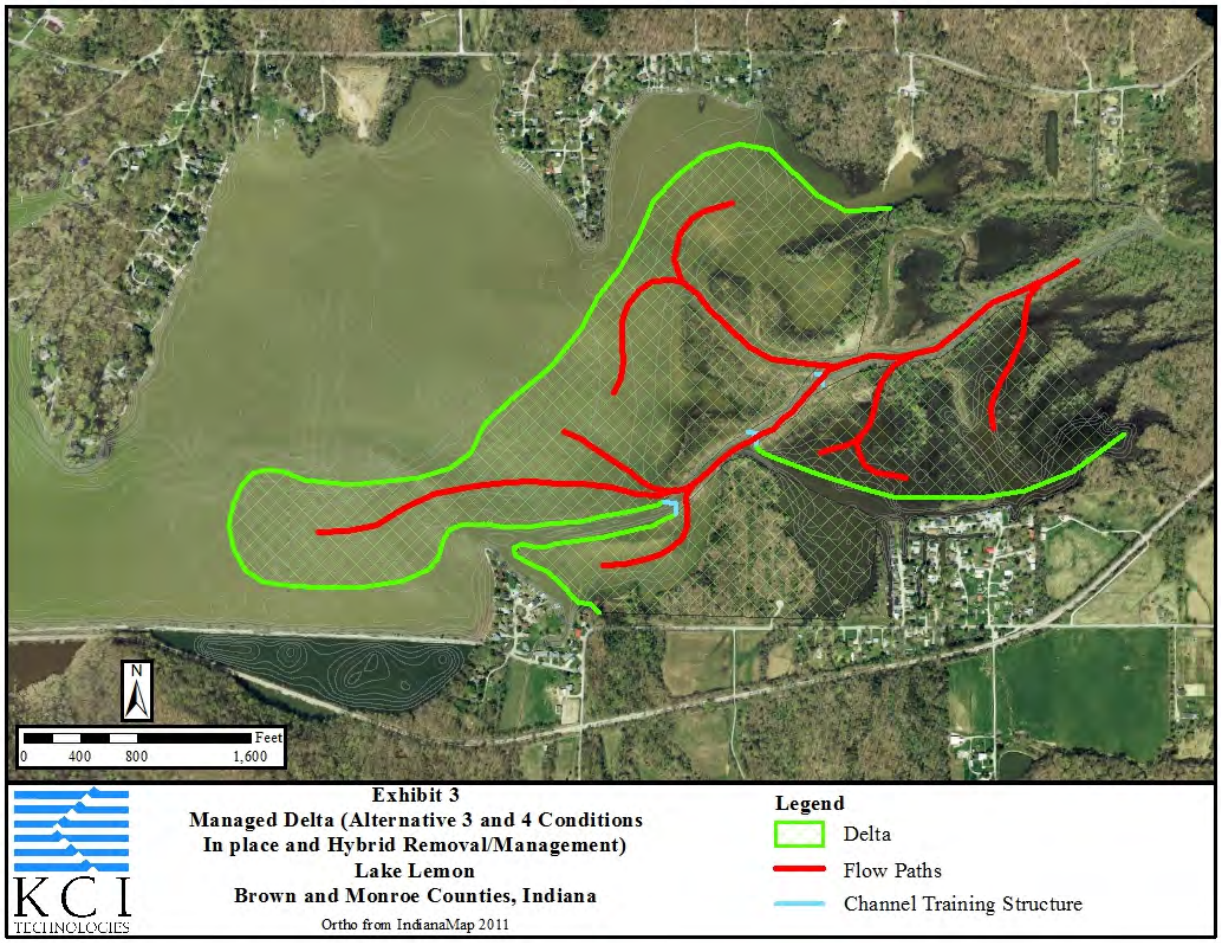
Recreational Use

- **Swimming** – the increase in water quality will increase water clarity and promote the development of SAV both in the area of the delta and in other near shore areas of the lake, however localized dredging will be used to control the extents of SAV beds maintaining the opportunities for swimming.
- **Boating** – A large area within the eastern end of the lake will be established as the delta management zone and reduce the net area in the lake available for boating.
- **Fishing** – The increased area of water in the 0 to 5' depth and increased volume of SAV will likely increase the net productivity for fish in the lake and overall fishable area.

Key Issues Resolution

- **Sedimentation** – This alternative provides an adaptive management approach to control of sediment inputs into the system. It manipulates natural fluvial geomorphic processes to create a controlled growth of a delta. It does not address the volume of sediment entering the lake but does manage the manner in which the sediment is influencing the lake.
- **SAV Growth** – This alternative would likely increase the growth of SAV in the lake, however that growth would be focused in delta management zone.
- **Water Quality** – With the growth of in lake vegetation and deep sequestration of nutrients in sediments, water quality would improve slightly.
- **Recreational Capacity** – The recreational capacity of the lake would improve for swimming and fishing, and decrease slightly for boating as open water is sacrificed for a managed delta.

Exhibit 3 – Managed Delta (Alternative 3 & 4 Conditions)



7.0 Schedule and Funding Needs

A preliminary cost estimate was prepared for each alternative based on the best available information. The cost estimates presented are an order of magnitude comparison between the various alternatives, refinements in objectives and detailed is required for financial planning purposes. A 20% contingency was applied to each estimate to account for unknown conditions. Five categories of cost were established as follows.

- Management – Cost associated with managing the work elements of the alternative that are above and beyond current lake management activities.
- Engineering – Costs associated with the development of hydrology/hydraulics, survey design plans/specifications.
- Permitting – Costs associated with the development of wetland, water quality, and or floodplain permitting.
- Dredging – Costs associated with removal of material via hydraulic dredging and translocation to containment area.
- Disposal – Costs associated with the development of containment areas for clean dredge material or removal to offsite locations.

All alternatives assumed a 4 year window of implementation, though they will likely need to continue indefinitely to maintain the status quo developed.

	2017	2018	2019	2020	Total	20%	Total Planning	Comments
Alternative					**Estimate**	**Contingency**	**Estimate**	
1 - Current								
Management	$50,000	$50,000	$50,000	$50,000	$200,000	$40,000	$240,000	
Engineering						$0	$0	
Permitting	$0	$0	$0	$0	$0	$0	$0	
Mechanical Dredging	$35,000	$35,000	$35,000	$35,000	$140,000	$28,000	$168,000	11,100 cy/year
Disposal	$25,000	$25,000	$25,000	$25,000	$100,000	$20,000	$120,000	
	$110,000	**$110,000**	**$110,000**	**$110,000**	**$440,000**	**$88,000**	**$528,000**	
2 - In Place Management								
Management	$80,000	$80,000	$80,000	$80,000	$320,000	$64,000	$384,000	
Engineering	$125,000	$50,000	$50,000	$50,000	$275,000	$55,000	$330,000	
Permitting	$20,000	$5,000	$0	$0	$25,000	$5,000	$30,000	
Mechanical Dredging	$77,500	$77,500	$77,500	$77,500	$310,000	$62,000	$372,000	25,000 cy/year
Disposal	$0	$0	$0	$0	$0	$0	$0	Assumes dredged material managed in lake delta
	$302,500	**$212,500**	**$207,500**	**$207,500**	**$930,000**	**$186,000**	**$1,116,000**	
3 - Dredging/Removal								
Management	$150,000	$150,000	$150,000	$150,000	$600,000	$120,000	$720,000	
Engineering	$100,000	$25,000	$0	$0	$125,000	$25,000	$150,000	
Permitting	$30,000	$0	$0	$0	$30,000	$6,000	$36,000	
Hydrualic Dredging	$1,125,000	$1,125,000	$1,125,000	$1,125,000	$4,500,000	$900,000	$5,400,000	25,000 cy per year plus 50,000 cy per year catch up
Disposal	$375,000	$375,000	$375,000	$375,000	$1,500,000	$300,000	$1,800,000	Assumes local disposal for 300,000 cy of material
	$1,780,000	**$1,675,000**	**$1,650,000**	**$1,650,000**	**$6,755,000**	**$1,351,000**	**$8,106,000**	
4 - Hybrid Removal/Management								
Management	$80,000	$80,000	$80,000	$80,000	$320,000	$64,000	$384,000	
Engineering	$125,000	$50,000	$50,000	$50,000	$275,000	$55,000	$330,000	
Permitting	$20,000	$5,000	$0	$0	$25,000	$5,000	$30,000	
Mechanical Dredging	$77,500	$77,500	$77,500	$77,500	$310,000	$62,000	$372,000	Removal of 25,0000 cy of material per year
Disposal	$56,000	$56,000	$56,000	$56,000	$224,000	$44,800	$268,800	Off site disposal of 25,000 cy of material per year
	$358,500	**$268,500**	**$263,500**	**$263,500**	**$1,154,000**	**$230,800**	**$1,384,800**	
	Assumptions;							
		$15 per cubic yard of material removed with Hydrualic Dredging						
		$5 per cubic yard for disposal for Hydraulic Dredging						
		$3.10 per cubic yard for material removed with Mechanical Dredging						
		$2.25 per curic yard for disposal for Mechancial Dredging						

8.0 Means and Methods

All alternatives presented include some aspect of sediment removal as a means of management. For the purposes of this analysis, hydraulic dredging was assumed as the primary means of removal. Hydraulic dredging provides the best efficiency for the volume of dredge management being considered. However, the costs of initiation i.e. purchase, maintenance, and disruption to ongoing lake operations was not considered. Further discussion regarding hydraulic dredge operations and its effect on current lake operations should be considered in detail. It is unlikely that removal via mechanical dredging will be able to effectively combat the current inflow of sediment in any meaningful capacity.

Of significant concern is the location of disposal areas for removed sediment. Alternatives 2 and 4 anticipate disposal to offsite locations. No significantly large areas are apparent in the local vicinity to aid in disposal of sediment. If removed material needs to be relocated to offsite locations, the costs of disposal could significantly exceed that currently estimated.

9.0 Management Considerations

There are numerous ancillary factors that are outside the scope of this analysis that should be considered as components to future management of the lake to further the objectives presented herein.

Watershed – The contributing watershed provides the vast majority of the sediment loading and water quality influence on the system. The issues within the watershed as a whole will need to be addressed through partnerships with watershed stakeholders by the Conservancy District. Development of management actions within the watershed to reduce the net volume of sediment in the lake should be considered as part of a long term management strategy.

Adjacent land uses – Water quality and localized sedimentation can be strongly influenced by adjacent land uses. Strong considerations should be made to address potential nutrient contributions from sanitary systems throughout the district. Shoreline management to minimize erosion should include localized stabilization and restrictions on near shore lake uses which increase wave action through wake action. These types of strategies should play a significant role in management of the sedimentation processes in the lake.

Water Level Management – Manipulation of the surface elevation of the lake plays a key role in many aspects of lake management including: fisheries, SAV management, water quality, etc. The effect of the backwater into the contributing drainage also effects the spatial extent and placement of sediments within the lake. Decreased lake elevations allow sediment to penetrate further into the lake pool, increasing both the extent of viable areas for colonization by SAV and allowing deposited material to become more stabilized, increasing the level of difficulty for removal. Careful consideration to balance pool elevations and sediment rating curves should be evaluated when applying this management technique.

High Resolution Graphics

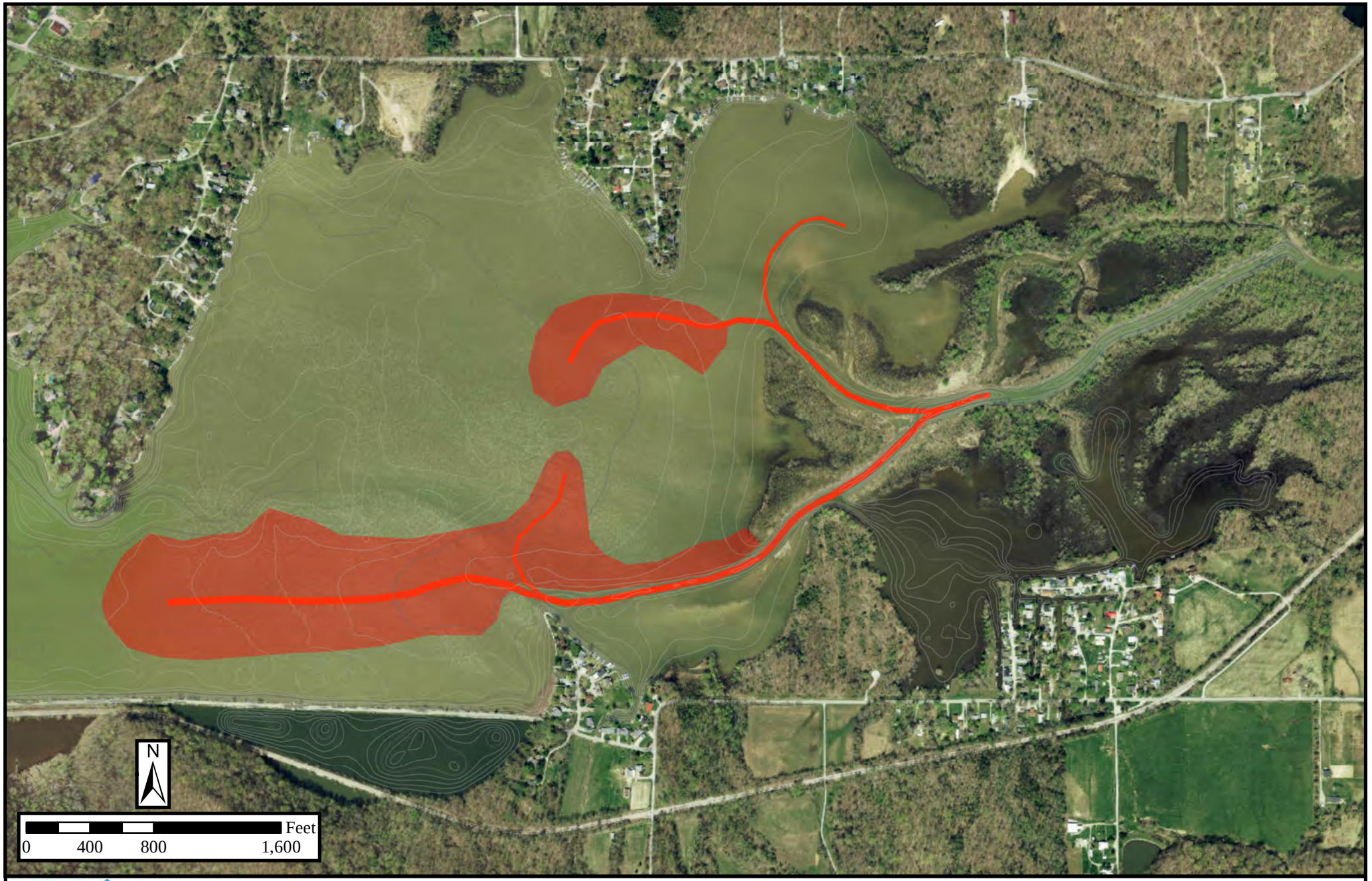


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Exhibit 1
Current Depositional Pathways
Lake Lemon
Brown and Monroe Counties, Indiana

Ortho from IndianaMap 2011

Legend

Sediment Flow Paths

Active Sediment Deposition Area

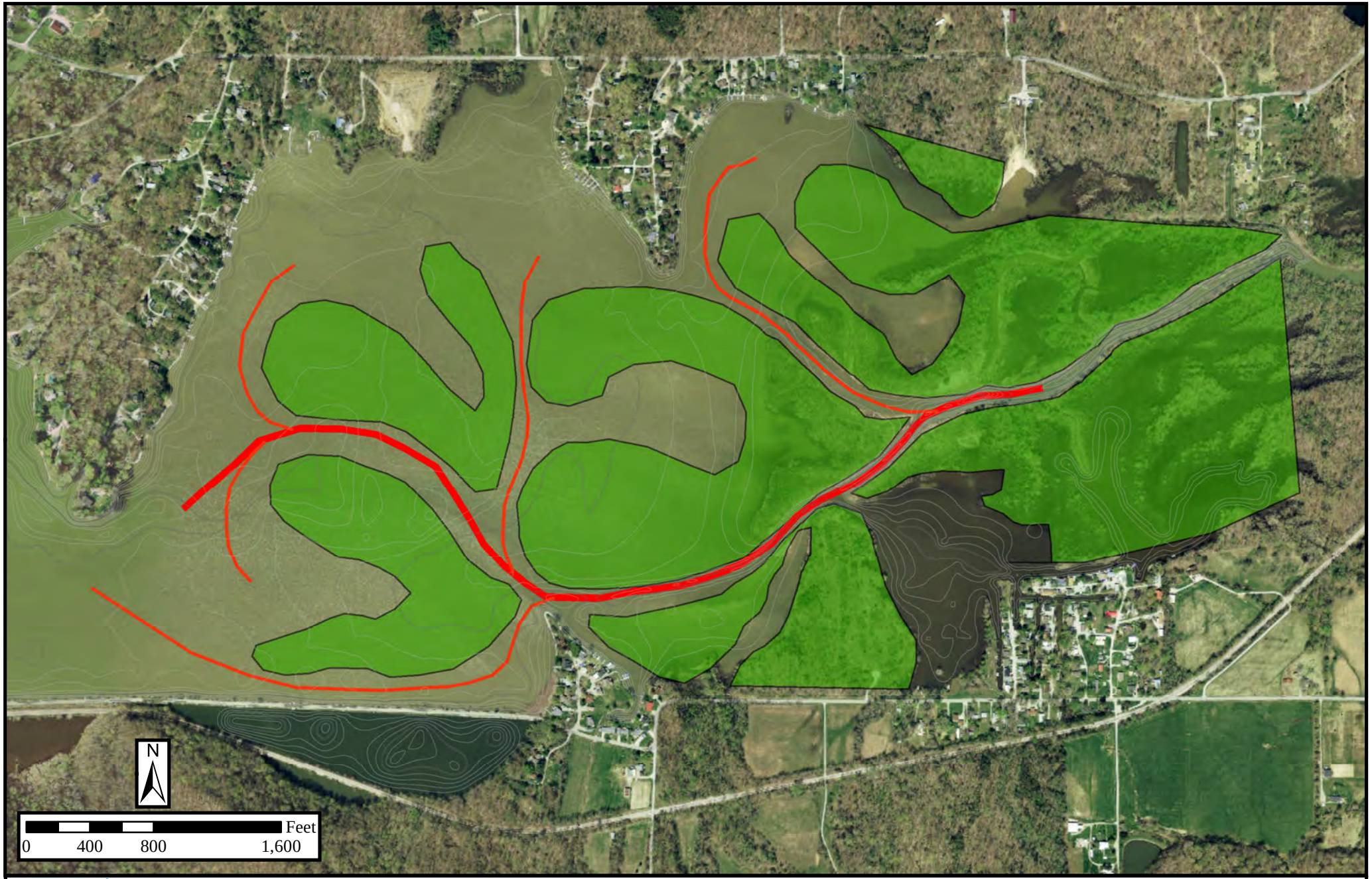

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Exhibit 2
Future Delta (Alternative 1 Condition - No Action)
Lake Lemon
Brown and Monroe Counties, Indiana

Ortho from IndianaMap 2011

Legend

- Sediment Flow Paths of Future Delta 20+ years
- Future Delta 20+ years

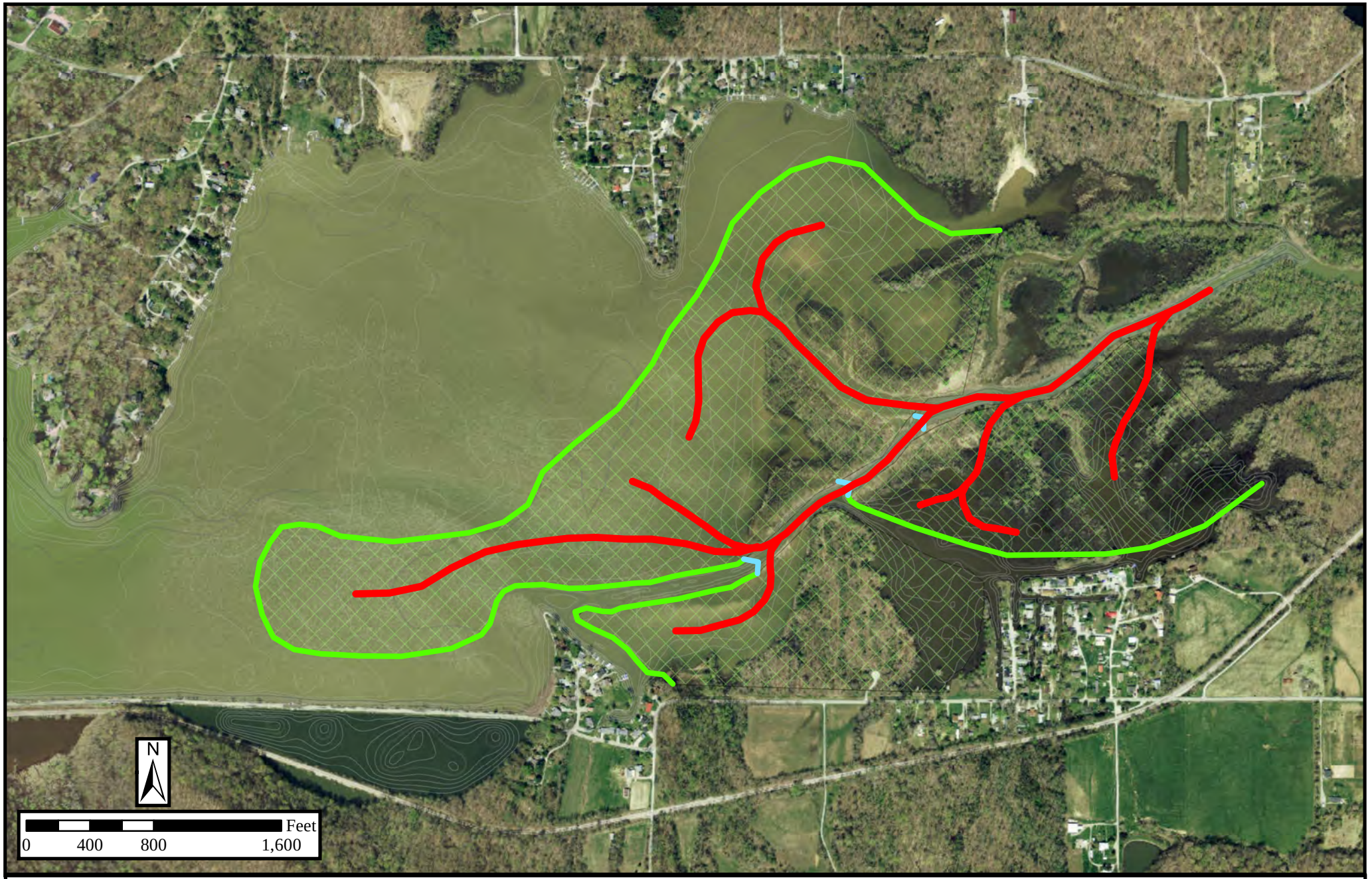

Exhibit 3
Managed Delta (Alternative 3 and 4 Conditions In place and Hybrid Removal/Management)
Lake Lemon
Brown and Monroe Counties, Indiana

Ortho from IndianaMap 2011

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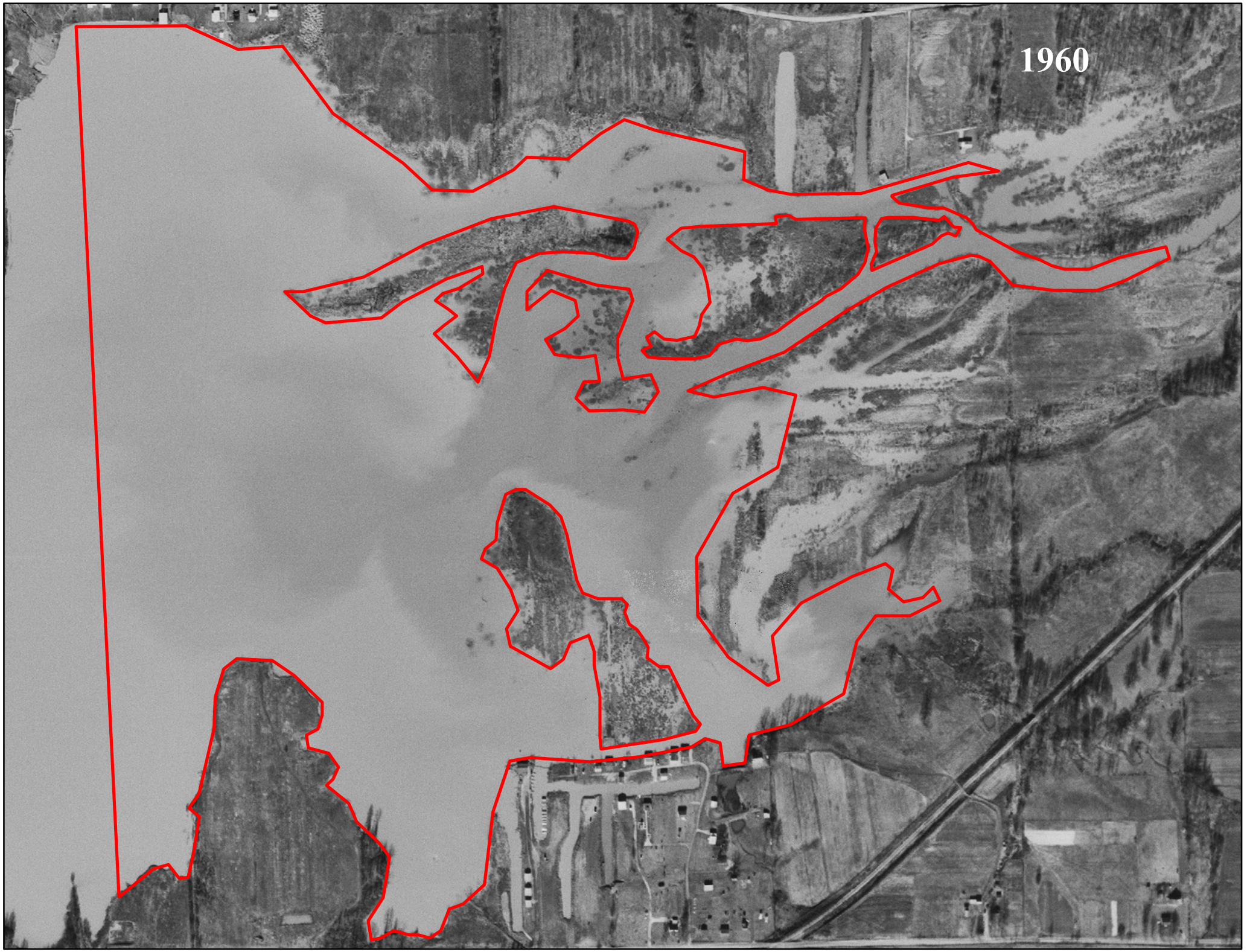
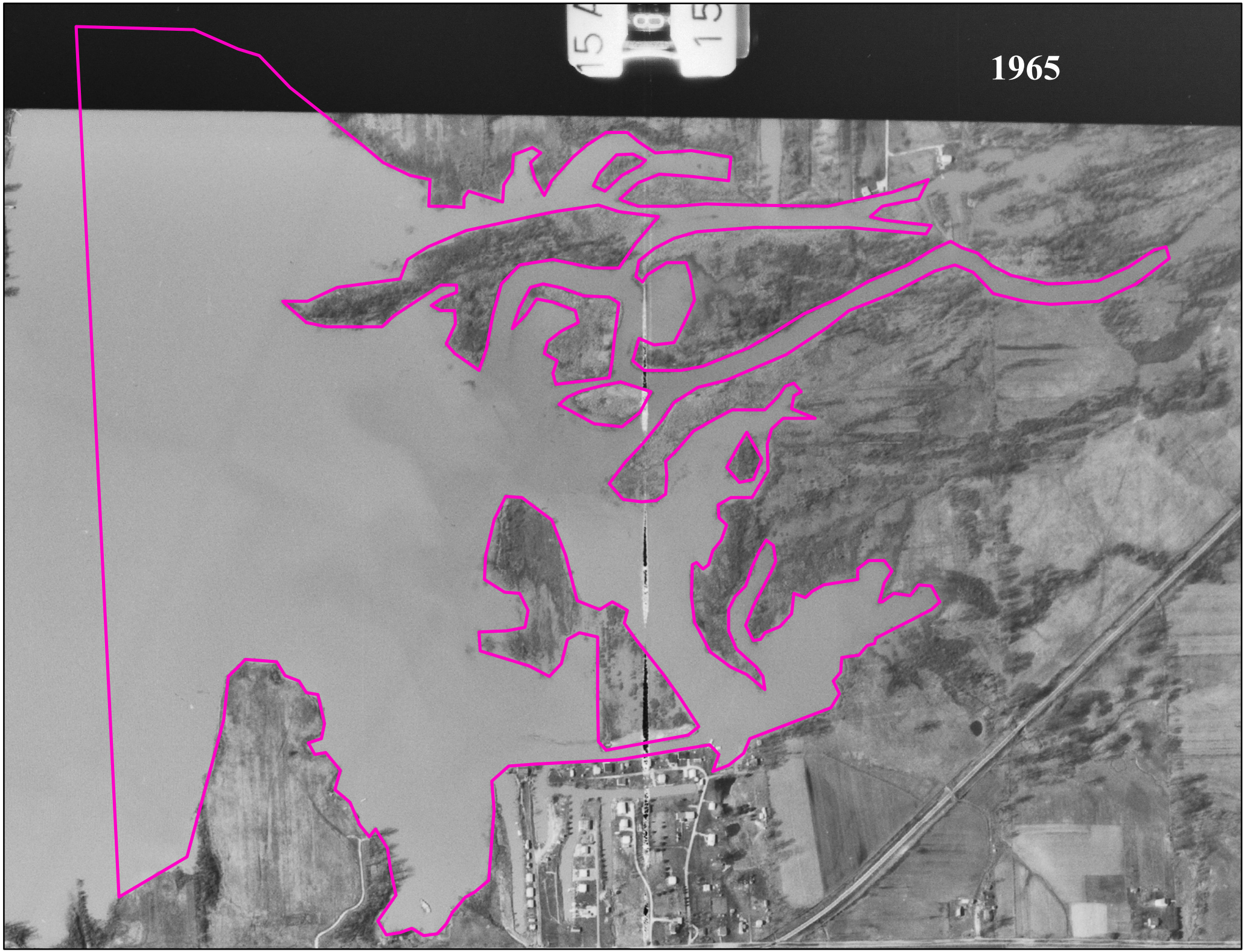
Legend

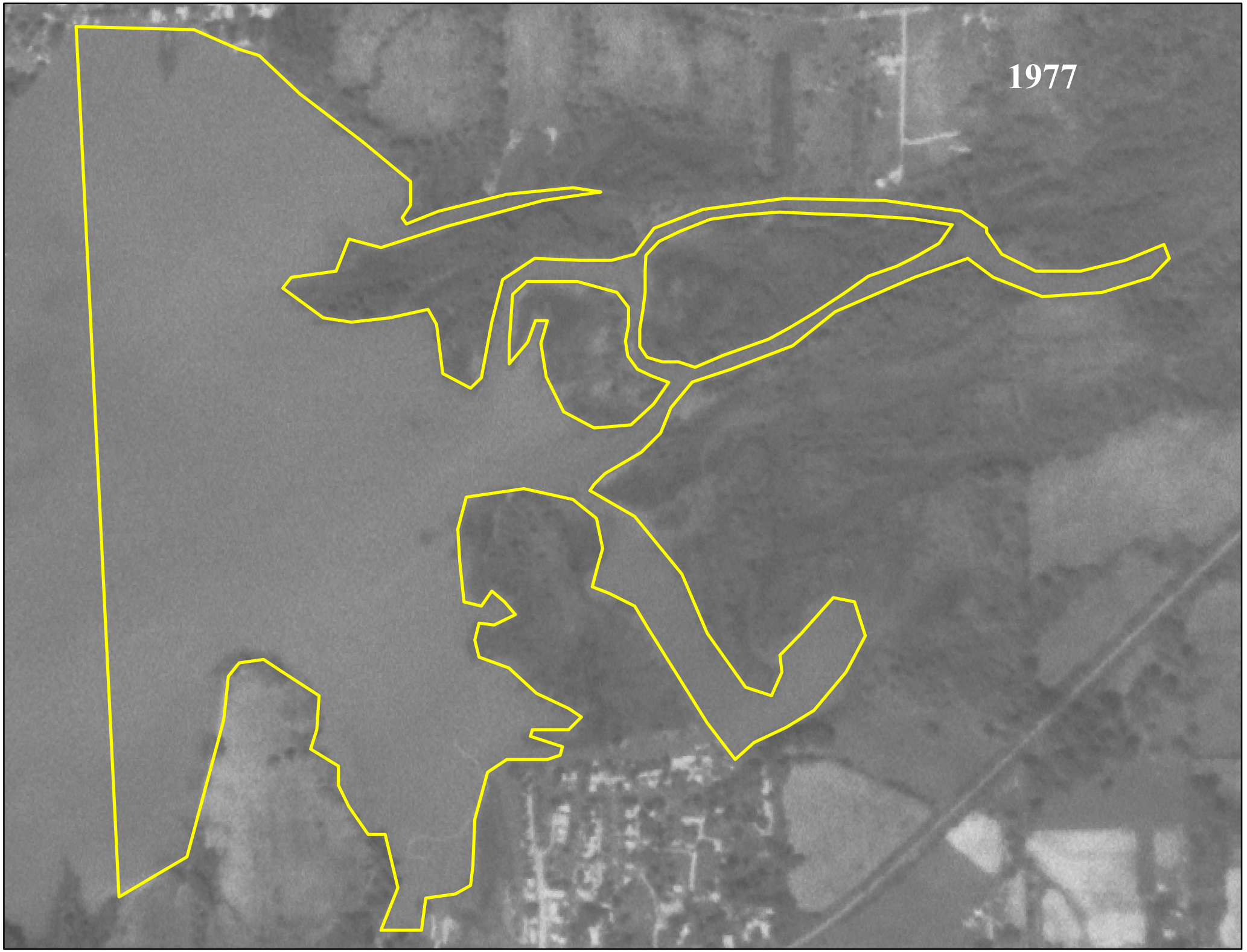
- Delta
- Flow Paths
- Channel Training Structure

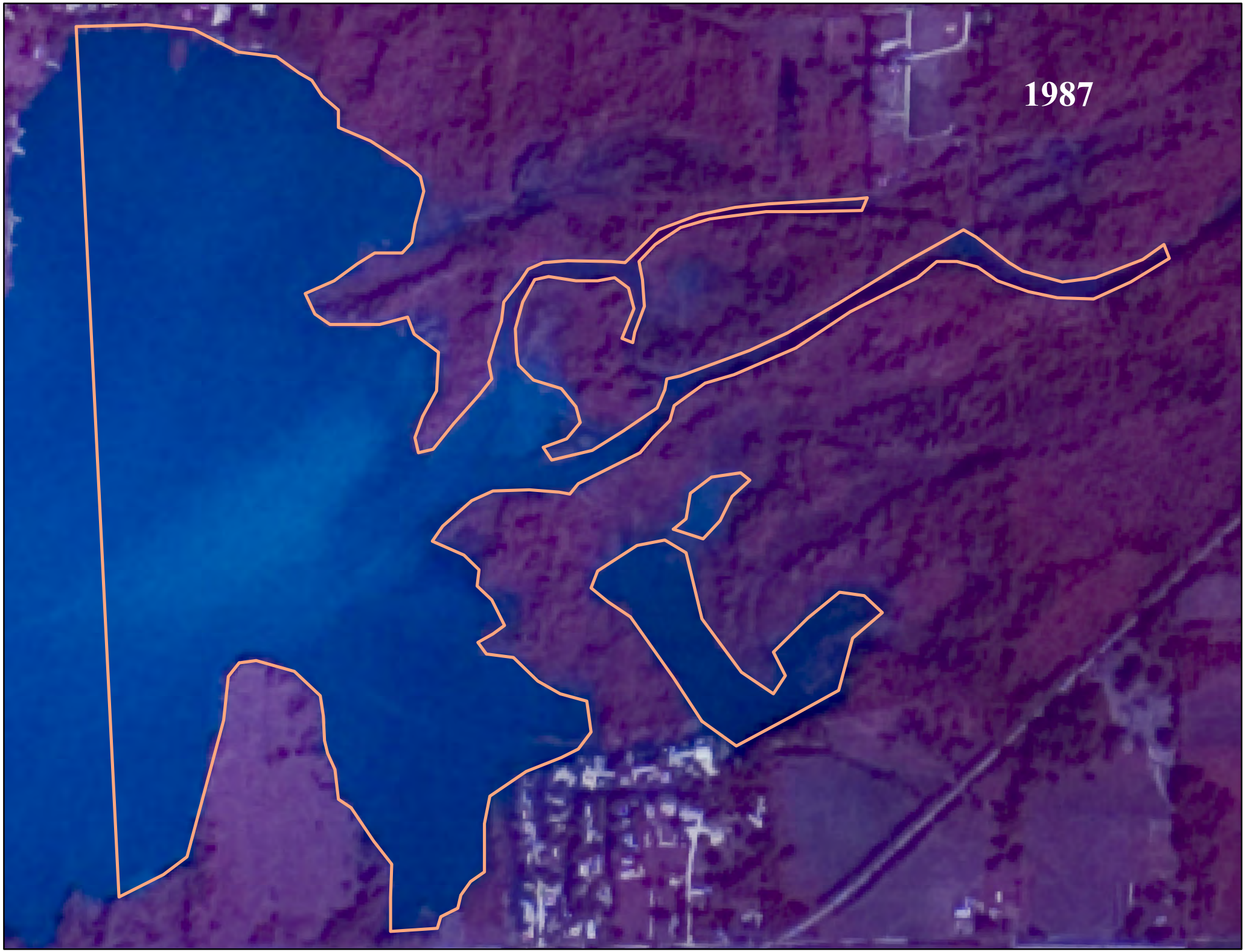
Historical Imagery

1960
1965
1977
1987
1998
2005
2011
2014


1960

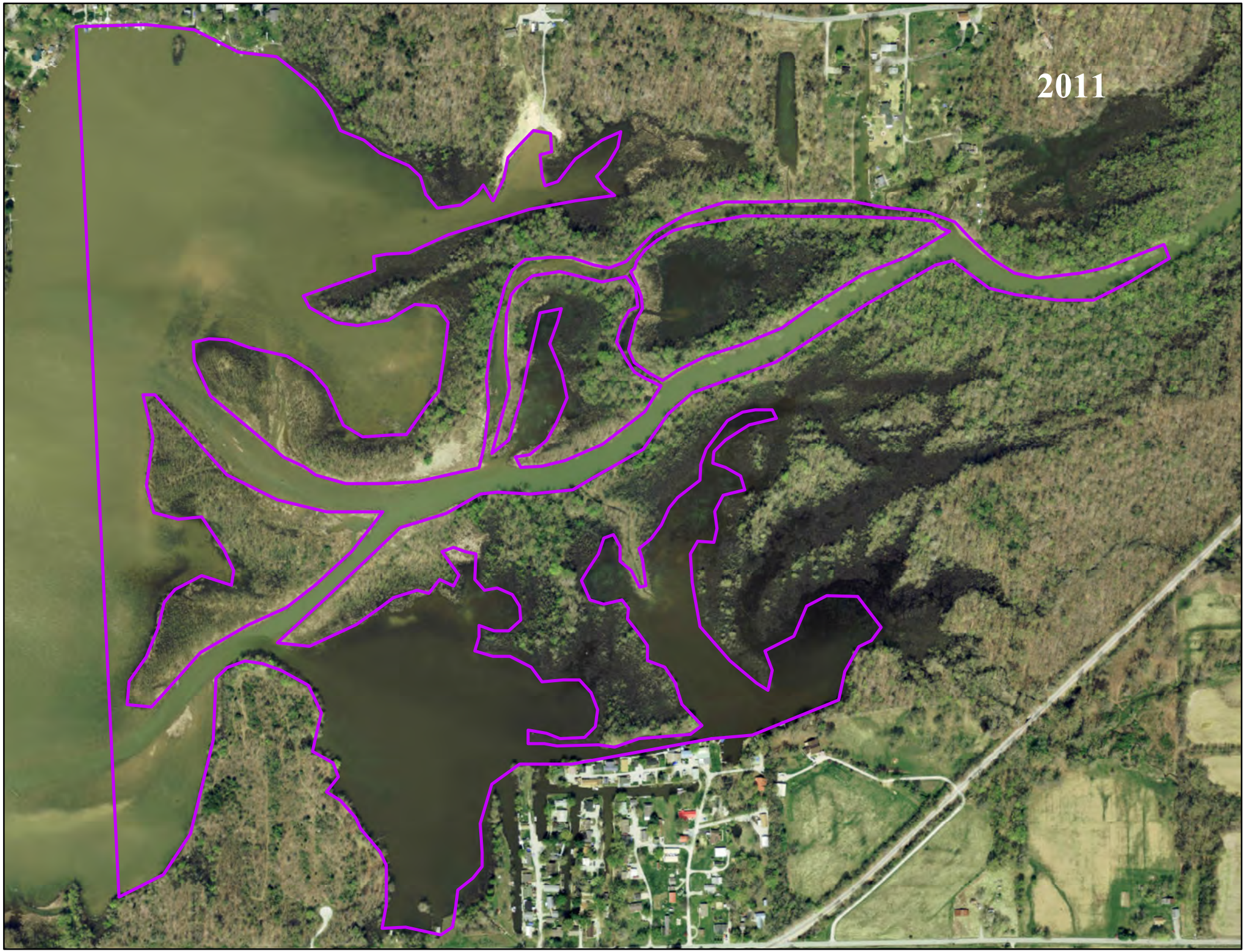

1965

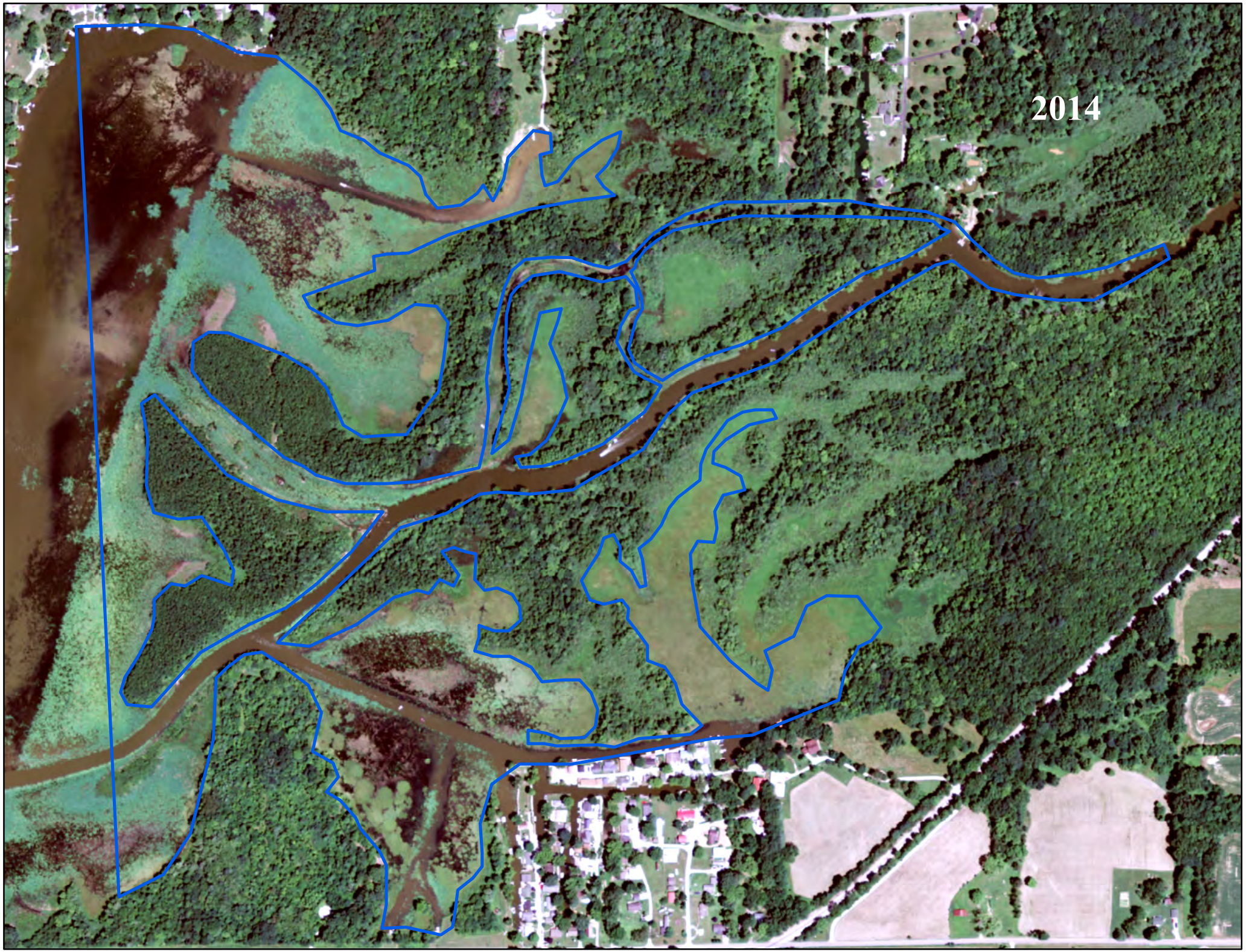

1977


1987


1998


2005


2011


2014