STATE OF MICHIGAN

ROSCOMMON COUNTY CIRCUIT COURT

IN THE MATTER OF:
THE WATER LEVELS OF HOUGHTON LAKE, HIGGINS LAKE, AND LAKE ST. HELEN

Case N°. 81-3003-CF

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VERIFIED MOTION TO INTERVENE BY ANNE AND RICHARD MEEKS, ELIZABETH WADE, DON CORRELL, PHILIP WILL, JULIE AND GARY SMITH, AND STAN GALEHOUSE AS INTERVENING RESPONDENTS AND COUNTER-DEFENDANTS AND BRIEF IN SUPPORT

MOTION

1. Proposed Intervening Respondents and Counter-Defendants, Anne and Richard Meeks, Elizabeth Wade, Don Correll, Philip Will, Julie and Gary Smith and Stan Galehouse (Intervenors) move to intervene in this proceeding by right and by permission, under MCR 2.209.

2. All of the proposed intervenors own riparian property on Higgins Lake; have interests that would be harmed by the granting of Movants' requested relief; and have a statutory right to intervene and present evidence in a proceeding affecting the lake level under Part 307 of the Natural Resources and Environmental Protection Act (NREPA), MCL 324.30701 *et seq*.

3. Anne and Richard Meeks own property at 101 Welt Street, Roscommon, Michigan. Elizabeth Wade co-owns property at 115 Earl Avenue, Roscommon, Michigan. Donald Correll owns property at 207 Sun Street, Roscommon, Michigan. Philip Will co-owns property at 115 Earl Avenue, Roscommon, Michigan. Julie and Gary Smith own property at 135 Timber Trail, Roscommon, Michigan. Stan Galehouse co-owns property at 104 Sovereign Park, Roscommon, Michigan. Each of these properties is on or proximate to the shore of Higgins Lake, and enjoys riparian rights on the lake.

4. The Movants in this case are a local gadfly, Eric Ostergren; a non-profit entity recently chartered by him with unknown membership; and a half dozen other persons with property near or on Higgins Lake. Movants request from the Court an order directing Roscommon County and its officials to show cause why they should not be held in contempt of the February 24, 1982 order governing the level of Higgins Lake. Movants assert that the lake level is or has been too low.

5. Intervenors own property on or around the northeast shore of Higgins Lake. Intervenors' properties currently suffer damage from high levels of erosion, which would be worsened if the Court granted relief requested by Movants.

6. Illustrative examples of this erosion damage are presented in Exhibit 2 to the intervenors' response in opposition to the motion to show cause.

7. Scientific documentation of the erosion problem is presented at page 20 of a report titled "Ecohydrologic Evaluation of Removing the Higgins Lake-Level Control Structure" by Dr. Anthony Kendall; Blaze M. Budd, and Dr. David Hyndman of Michigan State University (MSU report). The MSU report is attached as Exhibit 4 to the intervenors' response in opposition.

8. The factual basis for this motion is otherwise supported by the affidavit of Richard Meeks, which is attached as Exhibit 1 to the intervenors' response in opposition.

BRIEF IN SUPPORT

A. Standards for Intervention.

The Michigan Court Rules recognize both intervention by right and permissive intervention. Intervention by right is allowed when "a Michigan statute or court rule confers an unconditional right to intervene;" or "when the applicant claims an interest related to the property or transaction which is the subject of the action and is so situated that the disposition of the action may as a practical matter impair or impede the applicant's ability to protect that interest, unless the applicant's interest is adequately represented by existing parties." MCR 2.209(A)(1) and (3). Permissive intervention is allowed "when a Michigan statute or court rule confers a conditional right to intervene;" or "when an applicant's claim or defense and the main action have a question of law or fact in common." MCR 2.209(B).

For intervention by right or by permission, the court rule requires a timely motion, and case law requires that the applicant have standing. *Karrip v Cannon Twp*, 115 Mich App 726, 732; 321 NW2d 690 (1982). The intervention rules should be "liberally construed to allow intervention where the applicant's interests may be inadequately represented." *Neal v Neal*, 219 Mich App 490, 493; 557 NW2d 133 (1996). The decision lies within the discretion of the court. *Burg v B&B Enterprises, Inc*, 2 Mich App 496, 499-500; 140 NW2d 788 (1966). Intervenors meet all of the requirements described above, and so this Court should grant their request to intervene.

B. This Motion Is Timely.

To be timely, an intervenor must be diligent and act without unjustified delay. *Prudential Ins Co of America v. Oak Park Sch Dist*, 142 Mich App 430, 434; 370 NW2d 20 (1985). In *Karrip v Cannon Twp, supra*, the proposed intervenors filed their motion two months after the suit was initiated, and the Court held that the motion was therefore timely. 115 Mich App at 731. This motion is filed earlier in this proceeding than the one in *Karrip*. Therefore, this motion is timely.

C. Intervenors Meet the Requirements for Intervention by Right under MCR 2.209(A)(3).

Intervenors have a right to intervene in this proceeding because they claim an interest related to the property or transaction which is the subject of the action; they are so situated that the disposition of the action may as a practical matter impair or impede their ability to protect that interest; and their interest is not adequately represented by existing parties. Each of these elements is discussed below.

First, as discussed in the motion, above, intervenors claim interests related to the subject of this action that include protection of their property from erosion created by high water levels. As documented in the exhibits discussed in the motion and in the intervenors' response in opposition to the show-cause, this erosion damage already occurs at existing levels. Movants request that the level of Higgins Lake be raised even higher – including by "banking" water in the spring in excess of the existing lake level. The relief sought by Movants would only exacerbate the damage to intervenors' property.

Second, the disposition of this action may impair or impede intervenors' ability to protect their interests. If the relief Movants seek is granted, the worsening of erosion damage could become approved or even compelled by Court order. Such a development would impair or impede intervenors' ability to protect their property rights and interests now and in the future.

Third, intervenors' interests may not be adequately represented by existing parties. The burden of demonstrating inadequate representation is "minimal." *Karrip, supra,* 115 Mich App at 732. The rule only requires a showing that representation *may* be inadequate – not that it is in fact inadequate. Intervenors meet this minimal requirement because their interests are both narrower and different than those of Roscommon County. In the zoning case of *D'Agostini v City of Roseville*, the Michigan Supreme Court held that the interest of nearby residents would be inadequately represented by the city in a landowner's action contesting the denial of a rezoning, because the residents' interests were narrower than the city's interests:

> Moreover, we may consider that the city, the only defendant named in the counterclaim, is primarily concerned with the city-wide zoning pattern and cannot be guided solely by a consideration of individual hardships. Under such circumstances the legitimate objects and purposes of the city could well result in compromises to the detriment of individual rights…

396 Mich 185, 189; 240 NW2d 252 (1976). Likewise, in *Vestevich v West Bloomfield Twp*, the Court found that "even though the consent judgment does include terms that are obviously intended to address the concerns of nearby landowners, this does not mean that defendant could not have failed to address all concerns of all affected landowners." 245 Mich App 759, 762; 630 NW2d 646 (2001). Therefore, "defendant's representation of the intervenors' interests might well have been inadequate." *Id.*

As in *Vestevich* and *D'Agostini*, the County may not adequately represent intervenors' interests. The County is obliged to consider a broader scope of interests that includes all of the property owners on the lake and all of the residents and taxpayers in the County. Intervenors, by contrast, have much more particularized interests concerning the impact of Movants' requests on the intervenors' specific property.

D. Intervenors are also Entitled to Statutory Intervention of Right.

In addition to general intervention by right under the three factors outlined above, MCR 2.209(A)(1) confers a right to intervene where a Michigan statute so provides. Part 307 of NREPA is such a statute. Part 307 defines an "Interested person" to include "a person who has a record interest in the title to...land that would be affected by a permanent change in the natural or normal level of an inland lake." MCL 324.30701(1)(g). Section 7 of Part 307 requires the Court, in determining a normal lake level under the statute, to consider among other things: "testimony and evidence offered by all interested persons." MCL 324.30707(4)(i) (emphasis added). Thus, intervenors have a statutory right to present testimony and evidence in lake level proceedings.

Nor are the rights of lakefront owners limited just to participating in proceedings to establish a lake level. In the unpublished case of *In re Waters East Lake*, the Court of Appeals held that an owner of lakefront property was entitled to intervene in a proceeding brought under the trial court's continuing jurisdiction over an established lake level order under MCL 324.30707(5).[1] The *Waters East Lake* Court found that "As an abutting homeowner, Keech clearly had an interest in the lake level, and an individual has standing to invoke the circuit court's continuing jurisdiction over a matter that is already covered by a previous lake level order." *Id* at *2. The Court further found that while Part 307 "does not explicitly mandate notice requirements for continuing court actions. However, a fundamental right of due process is the opportunity to be heard, which

[1] *In re Waters East Lake*, unpublished opinion per curiam of the Court of Appeals issued June 11, 2013 (Docket No. 308021) (attached as Ex. 21 to Roscommon County's response.)

includes reasonable notice to interested parties of a proceeding." *Id* at *3. Therefore, the Court held that "even in the absence of an explicit directive in [Part 307], the Legislature intended that 'interested persons' would receive notice of any hearing that may affect their property rights." *Id.*[2]

E. Intervenors Also Meet the Requirements for Permissive Intervention.

In addition to intervention by right, permissive intervention is also appropriate. MCR 2.209(B) provides two circumstances in which a timely application for permissive intervention may be granted: "(1) when a Michigan statute or court rule confers a conditional right to intervene; and (2) when an applicant's claim or defense and the main action have a question of law or fact in common. Both circumstances are present here, and the Court has a "great deal" of discretion to grant permissive intervention. *Mason v Scarpuzza*, 147 Mich App 180, 187; 383 NW2d 158 (1985).

CONCLUSION AND RELIEF REQUESTED

For the reasons discussed above, intervenors respectfully request that they be granted intervention in this case, by right and by permission; and allowed to file their response in opposition to the show-cause motion; and all other relief that is appropriate under the circumstances.

[2] The Court in *Waters East Lake* ultimately found that the trial court's failure to grant the lakefront owner intervention was harmless because she was allowed to participate in the proceeding in essentially the same way as if she had intervened.

Respectfully Submitted,

June 10, 2019 By: ______________________

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RESPONSE IN OPPOSITION TO RELIEF REQUESTED IN MOTION TO SHOW CAUSE BY ANNE AND RICHARD MEEKS, ELIZABETH WADE, DON CORRELL, PHILIP WILL, JULIE AND GARY SMITH, AND STAN GALEHOUSE

I. Introduction

Movants in this case request from the Court an order directing Roscommon County and its officials to show cause why they should not be held in contempt of the existing order governing the level of Higgins Lake. The Movants in this case are, Eric Ostergren; a non-profit entity recently chartered by him of unknown membership; and a half-dozen other persons with property near or on Higgins Lake. Movants assert that the lake level is or has been too low to comport with the lake level order. None of them have offered any evidence that they were parties to the original proceeding that they now seek to enforce by contempt.

On May 28, 2019 an Order was issued directing Roscommon County to appear on June 12th and show cause why the Court should not hold the County and/or County officials in contempt and grant relief requested in the motion related to the lake level. The proposed intervenors are Anne and Richard Meeks, Elizabeth Wade, Don Correll, Philip Will, Julie and Gary Smith and Stan Galehouse. Intervenors own properties on the northeast shore of Higgins Lake. Intervenors' properties currently suffer damage from high levels of erosion, and granting relief to Movants will exacerbate this damage. Granting relief to Movants will also exacerbate impacts to fish populations in the Cut River, the flow of which is directly controlled by the lake level dam. Intervenors request that the Court deny Movants' request for sudden and abrupt action on the lake level, for three reasons:

1. The court-ordered level of Higgins Lake is not a fixed and minimum level. Rather, like any lake with a court-ordered level, it varies seasonally and within seasons. The lake level order is currently implemented in a way that comports with this reality. The County cannot be held in contempt for natural seasonal variation.

2. All property owners on Higgins Lake have an interest in the outcome of this proceeding, and a right to be heard under the statute governing lake levels in Michigan:

Part 307 of the Natural Resources and Environmental Protection Act (NREPA), MCL 324.30701 *et seq*. If Movants wish to change how the County has been implementing the lake level order, they need to file a petition to invoke the Court's continuing jurisdiction under that statute; and other interested parties need to be provided with notice and an opportunity to participate.

3. If the Court is inclined to exercise its continuing jurisdiction to review implementation of the lake level order, the statute lists a set of factors the Court should consider. Material precedents have been set on these issues since the lake level was originally established. Further, considerable scientific study has occurred regarding the level of Higgins Lake, the associated impacts to the Cut River, and the surrounding watershed. The Court should therefore revise or modify the lake level – or clarify the order's implementation – based on continued erosion damage to parts of the lake, updates to Part 307 case law, and better scientific information.

Each of these issues is discussed below, after a brief description of the erosion damage.

II. Substantial Erosion Damage is already Occurring on Higgins Lake from Levels that are too High.

In 2016, researchers at the Hydrology Laboratory in the Department of Geology at Michigan State University completed a study of Higgins Lake levels and effects of those levels on the Cut River. The study was titled "Ecohydrologic Evaluation of Removing the Higgins Lake-Level Control Structure" by Dr. Anthony Kendall; Blaze M. Budd, and Dr. David Hyndman (MSU report). The MSU report is attached as Exhibit 4. Researchers at the University of Michigan did a companion study on the Cut River. That study was titled "Study Job D.6 Prepare Habitat Models to Examine Fishery-Related Impacts" by Dr. Michael J. Wiley and Andrew J. Layman (UM study). The UM study is attached as Exhibit 5.

The MSU report stated: "Strong evidence for active shoreline erosion was observed at many locations around the lake." MSU report, p 90. The MSU report found "evidence of moderate to high erosion rates are present in four sections of Higgins Lake, on the eastern and northern sections of the North basin, the lower western section of the North basin, and a small strip of the southern portion of the North basin." MSU report, p 20. Figure 1.8.5 on page 20 of the report is a map of the various erosion zones around the lake. Likewise, the UM study stated: "Higgins Lake, in Roscommon County, has a controversial level of shore erosion which has been attributed to high water caused by an old lake-level control structure (dam) at the junction of the lake and the Cut River." UM study, p 1.

The MSU report found that concerns about the impact of high lake levels on shoreline erosion has existed for decades. For example, a 1956 Michigan Conservation Department report "voiced strong concerns that higher water levels would begin to erode the shoreline, since it was already evident as a problem." MSU report, p 7.

Exhibit 2 to this response is a series of photographs showing erosion damage on the northeastern shore of the lake – one of the locations identified in the MSU report. Some of the photographs show historical conditions compared to present conditions at the same location. (Locations can be verified by permanent structures or other landmarks in the photographs.) It can be readily seen from the photographs that current lake levels are already high enough to have substantially worn away parts of the shoreline, wiped out entire beaches, and damaged riparian property.

III. The Court-Ordered Level of Higgins Lake Is Not a Minimum Level and Has Never Been Managed as a Minimum Level.

The premise of Movants' motion – and all of their homemade data exhibits – is that the summer level of Higgins Lake is a fixed, minimum level. Therefore, Movants claim, every day in the summer that the lake is below that level is a "violation" of the order.[1] However, Movants' view has no basis in reality. The level of Higgins Lake – like any lake with a court-ordered level – is not fixed. It varies seasonally and within seasons. The lake level order has always been implemented this way.

The first lake level order on Higgins Lake was issued by Circuit Judge Guy Smith on June 30, 1926. A copy of that order is attached as Exhibit 3. The order states in pertinent part: "it is ordered and adjudged that the <u>natural</u> height and level of the waters of Higgins Lake is 1161.70 feet as established June 30, 1926."[2] (Emphasis added.) The reference to a "natural height and level" is significant because it reflects a natural condition – in which water is high in the spring and draws down over the course of the summer. The reference to a natural level contrasts with Movants' belief that the level must be artificially held at a single, fixed level for the entire summer or the County is in contempt of Court.

Next, the February 24, 1982 lake level order (Exhibit A to Movant's motion) states in pertinent part:

> It is hereby ordered and adjudged that the legal level of Higgins Lake, Roscommon County, Michigan, heretofore established at 1154.11 feet above mean sea level, be continued; provided, however, that said level be lowered to a level not less than 1153.61

[1] As the County points out, there is no evidence that the lake was below 1154.11 feet above sea level when Movants filed their contempt motion – calling into question the motive for seeking unilateral and immediate relief.

[2] The 1161.70 number was due to a mathematical error that was later corrected, as reflected in the 1982 order's reference of 1154.11 as the "heretofore established" level.

> feet, commencing on or about November 1 of each year, and restored to its legal level, commencing on or about April 15, or ice-out, which ever shall first occur, in each year.

Nowhere does the 1982 order state that the summer level is a minimum. That is important because the winter level *is* stated as a minimum: "not less than 1153.61 feet." (Emphasis added.) By contrast, the summer level is stated as a level that the water should be drawn up to, starting on or about April 15, or at ice out, whichever happens first.[3] This drawing-up occurs in the spring, when precipitation and snow-melt combine to ensure that the lake reaches its highest point of the year. Then, warm weather, dry conditions, and high evaporation rates combine to lower the lake from its peak over the course of the summer. Further, nowhere does the order allow "banking" of water above the stated level, in order to keep the lake in a flooded condition all summer.

Management of the lake level as a seasonal pattern, rather than an artificial fixed level, is consistent with the history of Higgins Lake. The MSU report notes that the former Michigan Department of Conservation (MCD) recognized this approach was already established practice by the 1950s:

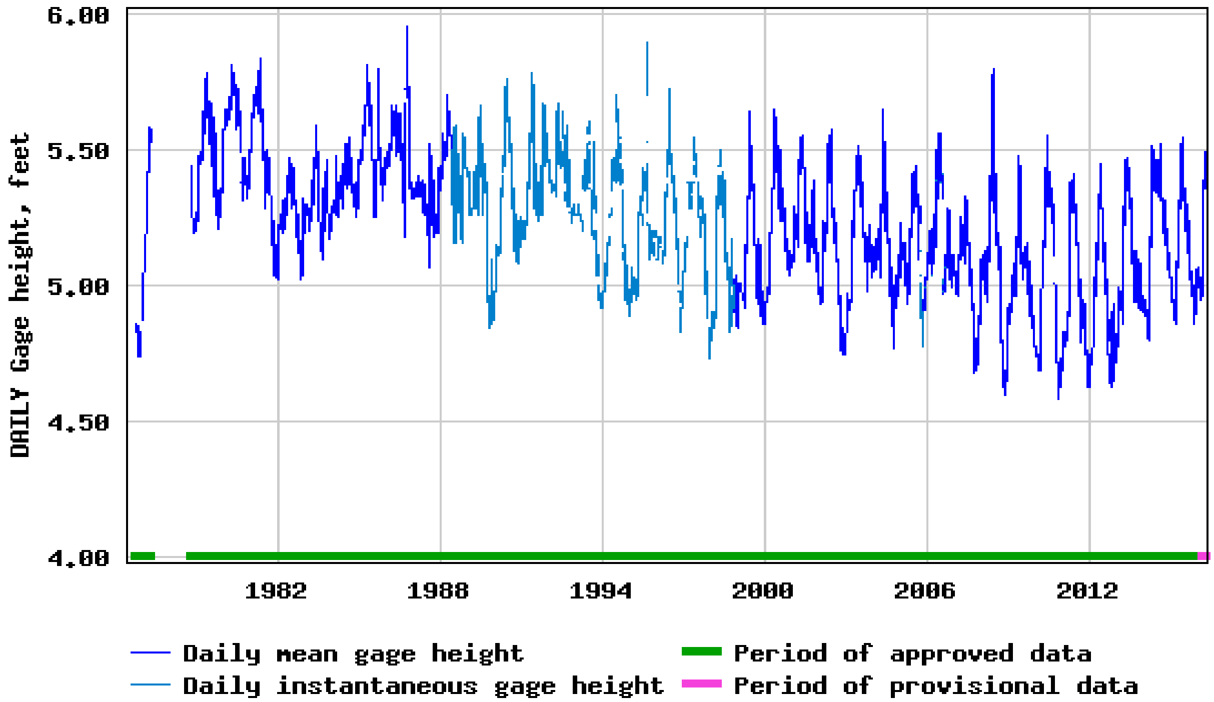
> The date on which dam management began its recovering toward the legal level was not mandated, but was an educated decision with practices that varied through time. MCD was very concerned of the inevitable damage to the lakeshore if lake levels were not at or below the legal level. The MCD viewed the legal level similar to a speed limit, not to exceed, but the ability to be lower.

MSU report, p 7 (emphasis added).

Further, this management practice is evident in the full set of historical data. Figure 1.3.1 on page 7 of the MSU report shows that the lake is drawn up during the wet season, and then it

[3] The order is curious in its use of "whichever shall first occur." Query how the lake could start being drawn up if ice was not out on April 15?

goes down over the course of the hotter, dryer summer season before being dropped to its winter level. This happens every year:



In *Glen Lake-Crystal River Watershed Riparians v Glen Lake Ass'n,* the Court of Appeals affirmed a trial court order that modified an established lake level order for managing Glen Lake. 264 Mich App 523; 695 NW2d 508 (2005). The Court quoted with approval the trial court's findings at length, including the finding that a court order setting a "natural level" should be managed to recognize the importance of seasonal fluctuations of the type just described. The Court stated:

> While the 1945 and 1954 Lake Level Orders have established 596.75 feet as the natural level of Glen Lake, management of this level has indeed recognized seasonal fluctuations and, for most of its history, a balanced management approach between the lake and river.

264 Mich App at 538.

Based on all of the above evidence, the Court should make four findings in the course of resolving this proceeding:

- Under the 1982 order, 1154.11 feet above sea level is the target for spring draw-up.
- After spring draw-up, the lake naturally declines over the course of the summer.
- 1154.11 is a maximum level; not a minimum level.
- Managing for variation over the seasons is the necessary and proper way to implement the lake level order.

IV. A Motion for Contempt is not a Legally-Sufficient Procedure for Addressing Issues Concerning an Established Lake Level Order.

Movants have no special status or standing to bring a motion for contempt in this case. None of them are governmental entities or named parties to the 1981 proceeding that culminated in the last lake level order. At most, some of the Movants may be "interested parties" as that term is defined in MCL 324.30701(g). At most, therefore, they have no greater rights in this matter than all property owners on Higgins Lake, who also have an interest in the outcome of this proceeding, and a right to be heard in it. Unless and until Movants correct the fatal procedural flaw in their motion, the Court should find they are entitled to no relief as a matter of law.

This proceeding is brought under the statute governing lake levels in Michigan: Part 307 of NREPA. Section 7 of that statute states in relevant part that the Court "shall have continuing jurisdiction, and may provide for departure from the normal level as necessary to accomplish the purposes of this part." MCL 324.30707(5). In *Glen Lake-Crystal River, supra,* the Court of Appeals held that parties with standing could invoke the Court's continuing jurisdiction over an established lake level – in that case, to modify management practices concerning the level. 264 Mich App at 531.

Lakefront property owners are statutorily defined as "interested parties" to a lake level proceeding. MCL 324.30701(g). As interested parties, they have a statutory right to present testimony and evidence in a lake level proceeding. MCL 324.30707(4)(i). If Movants wish to change how the County has been implementing the lake level order for decades, they need to file a petition to invoke the Court's continuing jurisdiction under that statute; ask for a hearing; and all other interested parties need to be provided with notice and an opportunity to participate.

As also discussed in Intervenors' motion to intervene, the Court of Appeals in *In re Waters East Lake* held that an owner of lakefront property was entitled to intervene in a proceeding brought under the trial court's continuing jurisdiction over an established lake level order.[4] The *Waters East Lake* Court found that "As an abutting homeowner, Keech clearly had an interest in the lake level, and an individual has standing to invoke the circuit court's continuing jurisdiction over a matter that is already covered by a previous lake level order." *Id* at *2. The Court further found that while Part 307 "does not explicitly mandate notice requirements for continuing court actions. However, a fundamental right of due process is the opportunity to be heard, which includes reasonable notice to interested parties of a proceeding." *Id* at *3. Therefore, the Court held that "even in the absence of an explicit directive in [Part 307], the Legislature intended that 'interested persons' would receive notice of any hearing that may affect their property rights." *Id.*

Similarly, in this case, Movants seek to abruptly change the way in which the County has always managed the natural level of Higgins Lake. Such precipitous and hasty action – if taken – would impact the property rights of over one thousand other Higgins Lake property owners. Under

[4] *In re Waters East Lake*, unpublished opinion per curiam of the Court of Appeals issued June 11, 2013 (Docket No. 308021) (attached as Ex. 21 to Roscommon County's response.)

Glen Lake-Crystal River and *Waters East Lake*, such action requires a notice, a hearing, and an opportunity to present testimony and evidence.

V. If the Court is Inclined to Take Action, it should Update the Lake Level Order or Clarify its Implementation.

If the Court is inclined to exercise its continuing jurisdiction over the lake level order, *Glen Lake-Crystal River* states that the Court should base its decision on the factors in MCL 324.30707(4). Those factors are:

a. Past lake level records, including the ordinary high-water mark and seasonal fluctuations.
b. The location of septic tanks, drain fields, sea walls, docks, and other pertinent physical features.
c. Government surveys and reports.
d. The hydrology of the watershed.
e. Downstream flow requirements and impacts on downstream riparians.
f. Fisheries and wildlife habitat protection and enhancement.
g. Upstream drainage.
h. Rights of riparians.
i. Testimony and evidence offered by all interested persons.
j. Other pertinent facts and circumstances.

As discussed above, material precedents have been set on these issues since the lake level was originally established. Further, considerable scientific study has occurred regarding the level of Higgins Lake, the associated impacts to the Cut River, and the surrounding watershed. The UM study assessed impacts to fish populations in Higgins Lake and the Cut River, and concluded that lower water levels in the lake would not have a significant impact on fish in the lake, but would substantially improve fish populations in the river:

> While the fish habitat WUA [weighted useable area] analysis in Higgins Lake suggested minimal sensitivity to changes in WSE [water surface elevations], the WUA analysis for the Cut indicates that fish habitat has a strong dependence on instream flow rate.

UM study, Exhibit 5, p 18.

As noted just above, the factors enumerated in Part 307 specifically include downstream flow requirements and fisheries and wildlife habitat protection and enhancement – factors that were not included in the statute when the original lake level order was issued. MCL 324.30707(4)(e)-(f). In *Glen Lake-Crystal River,* the Court of Appeals (again quoting with approval the trial court) recognized that modern lake level management must take into account the health of the outflow stream:

> A key finding by this Court is that the Crystal River is not merely a tool used to maintain Glen Lake's water level. Rather, it is a viable part of the watershed, and, the management of Glen Lake's water level must be done so as to minimize environmental consequences to both the lake and the river.

264 Mich App at 537.

In this case, if the Court takes any action with respect to the level of Higgins Lake, the Court should revise or modify the lake level – or clarify the order's implementation – based on continued erosion damage to parts of the lake, updates to Part 307 case law, and better scientific information.

CONCLUSION AND RELIEF REQUESTED

For the reasons discussed above, Intervenors respectfully request that the Court deny any further relief to Movants on the motion to show cause; make the findings requested in this response; open a proceeding to revise the lake level and/or management of the lake level; and take further action as appropriate under the circumstances.

Respectfully Submitted,

June 10, 2019

By: ______________________________

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EXHIBIT
1

STATE OF MICHIGAN

ROSCOMMON COUNTY CIRCUIT COURT

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AFFIDAVIT OF RICHARD MEEKS

Richard Meeks, being sworn, states:

1. I am a riparian property owner on Higgins Lake. My address is 101 Welt Street, Roscommon, Michigan.

2. I retained Olson, Bzdok & Howard, P.C. on June 8, 2019.

3. I have owned my property on Higgins Lake since September 1992. This property has been in my wife's family since 1964.

4. I am familiar with the facts contained in the Motion to Intervene and the Response in Opposition to Relief Requested in Motion to Show Cause and can attest to these facts as true.

5. I further attest that the photos contained in Exhibit 2 have been in my custody or taken by my wife and neighbors. I am personally familiar with the areas and condition depicted in the photographs.

6. If called as a witness, I could competently testify to the facts herein.

The above is true to the best of my knowledge, information and belief.

Date: June 10, 2019

____
Richard Meeks

STATE OF MICHIGAN
COUNTY OF ROSCOMMON

Acknowledged before me on June 10, 2019 by Richard Meeks.

____
Karla L. Gerds, Notary Public
Grand Traverse County, Michigan
Commission Expires: November 13, 2024
Acting in Roscommon County, Michigan

EXHIBIT
2

Taking "The Violet" out of the water.
Newell Barnard helping.

Cottage Grove Camp,
Higgins Lake, Mich.

July 16, 2008

On the beach at the
A. Barnard dock.

Cottage Grove Camp
Higgins Lake, Mich.

July 16, 2008


07.04.2008

EXHIBIT 3

In the matter of the Petition of the Boards
of Supervisors of the County of Roscommon
and County of Crawford To determine
and establish the natural height and
level of the waters of Higgins Lake

The petition of the above named Boards of Supervisors of Roscommon and Crawford Counties having come on to be heard, after reading the same, and hearing the proofs in support thereof, and it appearing by the affidavits of D. Eugene Matheson, publisher of the Roscommon Herald-News, and O. P. Schumann, publisher of the Crawford Avalanche, that notice of the hearing of said petition was duly published as required by law; and it further appearing from the proofs adduced that the height and level of the water of said Higgins Lake as of June 30th, 1926, to-wit, 1161.70 feet according to the data of the Fargo Engineering Company, was the natural height and level of the waters of Higgins Lake;

Therefore, it is ordered and adjudged that the Natural height and level of the waters of Higgins Lake is 1161.70 feet as established June 30th, 1926.

Thereupon Court adjourned until Wednesday morning at 9 o'clock.

Read, approved and signed in open court.

Wm Haughton.
Deputy Clerk

Guy E Smith
Circuit Judge

Circuit Court Order Establishing Legal Level of Higgins Lake [94].wpd

In the matter of the Petition of the Boards
of Supervisors of the County of Roscommon
and the County of Crawford to determine
and establish the natural height and level
of the waters of Higgins Lake

The petition of the above-named Boards of Supervisors of Roscommon and Crawford Counties having come on to be heard, after reading the same, and hearing the proofs in support thereof, and it appearing by the affidavits of D. Eugene Matheson, publisher of the Roscommon Herald-News, and O. P. Schumann, publisher of the Crawford Avalanche, that notice of the hearing of said petition was duly published as required by law, and it further appearing that from the proofs adduced that the height and level of the waters of said Higgins Lake as of June 30, 1926, to-wit, 1161.70 feet according to the data of the Fargo Engineering Company, was the natural height and level of the waters of Higgins Lake.

Therefore it is ordered and adjudged that the natural height and level of the waters of Higgins Lake is 1161.70 feet as established June 30, 1926.

Thereupon Court adjourned until Wednesday morning at 9 o'clock.

Read, approved and signed in open court.

/s/Wm. Houghton — /s/GuyE. Smith
Deputy Clerk — Circuit Judge

Circuit Court Journal 3 pp. 172-3 [94]

EXHIBIT 4

Final Report to the Muskegon River Watershed Assembly

May 27, 2016

Ecohydrologic Evaluation of Removing the Higgins Lake-Level Control Structure

Anthony D. Kendall, Blaze M. Budd, and David W. Hyndman

Introduction

Higgins Lake, in Roscommon County, has experienced significant shoreline erosion, some of which has been attributed to high water caused by a lake-level control structure (dam) at lake's outlet into the Cut River. The erosion has been severe enough to concern the Higgins Lake Property Owners Association, and the structure's operations are non-compliant with the provisions of the Muskegon River Watershed Plan (O'Neal 2003). The effects of the erosion and accompanying disturbance to the lake bottom, surrounding vegetation, animal species, and neighboring aquatic habitats have had little study since the construction of a permanent dam in 1936. This is despite the fact that the lake and its environs provide significant fishing, recreational and economic benefits to the citizens of Michigan. For these reasons, we conducted a study of the area that included hydrology, wildlife, vegetation, and weather to provide a scientific basis to help local decision makers alleviate the erosion, minimize ecosystem impacts, and maximize recreational benefits from the lake.

As one of the largest inland water bodies in Michigan, Higgins Lake has a surface area of 10,186 acres. It includes a number of tributaries, and discharges into the Cut River, which then runs through Marl Lake and joins with Backus Creek, before entering Houghton Lake. The basis for the initial assessment that enhanced shoreline erosion exists is that the dam maintains artificially high water levels, causing a significant increase in the energy of waves striking shore. When heavy rain events occur, artificially high water elevations are raised further, thus exposing even larger areas of shoreline to enhanced erosion. In some areas, it appears that the shoreline has receded by 35 feet or more and portions of shoreline have been hardened with seawalls and/or rip-rap to limit erosion.

The Higgins Lake Property Owners Association (HLPOA) contacted DNRE Fisheries Division with their concerns regarding the significant shoreline erosion in 2010. Records and data from the 1939 Fisheries Division survey of the lake indicate reductions have occurred in the amounts of gravel bottom, floating vegetation, and emergent vegetation. In the interim, studies of the lake level control dam were done in 1956, 1969, and 1995.

Manipulation of the dam's height to control water levels in Higgins Lake historically resulted in significant variations to the streamflow in the Cut River, including periods with little to no outflow, which affects its fish communities and vegetation, along with those of Marl and Houghton Lakes. This is a concern for the fish species that use the Cut River for spawning, including walleye, a recreational sport fish that helps support an important fishery in Houghton Lake.

This study seeks to apply state-of-the-art data collection tools and computer models to measure the state of the Higgins Lake and Cut River systems, to model hydrologic and ecological function of these systems, and to simulate changes that would likely result from altered dam management or dam removal.

Findings By Task

In this report, we describe the findings of this project based on extensive evaluation of data and models for Higgins Lake, along with its basin and outlet. Our findings are described within each subsection, and summarized at the end of each Task. Tasks 1 through 5 are summarized in this report, as these were hydrology-related tasks completed by Michigan State University. Task 6, fish habitat modeling, was described in an earlier addendum to this report by the University of Michigan. Task 7, surveying members of the Higgins Lake Property Owners Association, is described in brief here as well, along with a presentation of overall survey results. Tasks 8 and 9 pertain to reporting, public presentations, and scientific manuscripts and publications which have been discussed in earlier interim reports. Task 10 is associated with administrative work conducted by the Muskegon River Watershed Alliance.

Task 1: Review Hydrogeologic, Environmental, and Engineering Data

This section describes the synthesis of existing data for the region. Data were compiled that describe the lake, its outlet (the Cut River), and the surrounding hydrogeologic system.

1.1: Outlet Control Structure Studies

Multiple engineering reports have been completed on the operation and maintenance of the the Higgins Lake control structure, which sits at the head of the Cut River (1940, 1941,1956, 1995, 2007). The 1956 report from the Michigan Department of Conservation Engineering and Architecture (MDCEA) titled "*Higgins Lake Level Control, Roscommon and Crawford Counties, Preliminary Engineering Investigation*" mentioned the the two previous studies; "*Memorandum on Proposed Outlet Dam for Higgins Lake, Roscommon County, Michigan"* (Ayers,Lewis,Norris, and May; 1940) and "*Control of Level of Higgins Lake"* (Fargo Engineering Co.;1941). These reports presented designs for new control structures to allow for more manageable openings. However, the operating improvements were not implemented.

Study from Spicer

The main purpose of the Spicer group report #118475SG2010 was to evaluate the structural integrity, functionality, and effectiveness of the Higgins Lake control structure. It described various measures of water loss from the lake, and provided recommendations about dam alterations that would retain more water.

Evaporation: Spicer used MSU's enviro-weather website for a station in Arlene Michigan (26 miles W-SW of Higgins Lake) to estimate the potential evapotranspiration (PET) for July and August of 2010. The PET rates for these months were 0.1 to 0.3 in/day. Spicer then removed transpiration from the calculations and relied on pan evaporation measurements at a NOAA station located 24 miles to the W-SW, outside of Lake City, Station ID GHCND:USC00204502. Their calculated monthly average evaporation during the summer for the recording period from 1967 through 2008 was 0.11 in/day with the highest rates of 0.15 in/day in July.

Wave Loss: Within Table 1 of the Spicer report, wave height with water loss over the dam was estimated for a sustained 24 hour period to be ~ 0.05 in/day

Spicer Report Table 1: Wave loss over the dam as a function of wave height.

Height (inches)	24-hr Loss (in/day)
4	0.03
6	0.05
9	0.08
12	0.10
18	0.16
24	0.21

Low Flow Channel Outlet: The low flow channel is approximately 4.75 feet wide and 3 feet high to the top of the dam catwalk. But the depth of flow through from concrete sill when the lake is at summer legal lake level is ~2 feet. Spicer calculated that the flow during summer levels would be 33 cfs, or 28 cfs with 1 foot of tailwater. Assuming no inflow, the lake level would drop 0.08 in/day at 33 cfs flow, and 0.07 in/day at 28 cfs flow. However, this drawdown calculation does not consider substantial inflows from groundwater and the the 2 tributaries, Big Creek and Little Creek.

Spicer Report Table 2: Summary of normal water loss from Higgins Lake

Water Loss	Depth Loss (in/day)
Evaporation	0.10-0.15
Wave Action	0.05
Low-Flow Channel	0.07

The main conclusion of this Spicer report was that the lake levels are affected by evaporation during the summer months and flow through the low flow structure of the dam, followed by wave loss. The report does not include any new measurements of Cut River flow to compare with outflow estimates from the dam at various lake elevations or dam orientations.

The 1995 report also found that flow out of Higgins Lake is limited by the capacity of the Cut River when flows exceed 110-120 cfs. This is due to the culverts at East Higgins Lake Drive.

1.2: Outlet Control Structure Description

The current Higgins Lake Control Structure consists of a series of 6 manipulable openings plus a 4.75 foot wide low flow channel (Figure 1.2.1). The naming scheme of the openings were adopted based on the daily records of the dam kept by the board of commissioners. The numbered scheme begins from the West to East. 1 through 3 are the stop log gates, 4 through 6 are the flop gates. These gates can be operated independently of each other, with typical configurations of gates 4, 5, or 6 open and with any combination of gates. Gate 4 is 15.5 ft wide, whereas gates 5 and 6 are 17.5 ft wide. Gates 1 - 3 measure 5 ft wide and are rarely opened, and in general impact flows much less than the flop gates opened. The dam structure has had various configurations through time (e.g., Figures 1.2.2 - 1.2.3).

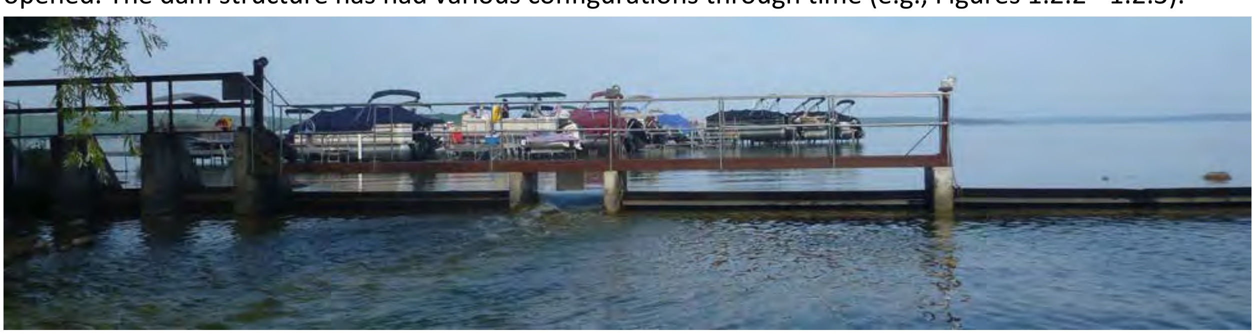


Figure 1.2.1. Image of the 2015 outlet control structure looking toward Higgins Lake from the Cut River. The low flow structure is in the center of the picture.

Figure 1.2.2. Image of upstream and downstream side of the stop-log gates (2010 Spicer report). The flow through this section is governed by the use of 5 foot wide wood planks, which are rarely removed due to their unwieldy size and weight.

Figure 1.2.3. The outlet at Cut River, during a period when the full dam structure was not in place.

To quantify potential lake level drop scenarios, the outlet control structure was measured and surveyed, in particular the role of rocks adjacent to and within the structure were examined. Lakeward of the control structure, boulders form a loose pavement and are used as riprap along the sides of the shore and entry of the outlet. The presence of these are thought to be from the previous low head and rock dams as an attempt to keep lake levels high during dam out durations, see Figure 1.2.2. The boulders and cobbles are at approximately the same elevations of the flop gate sills along the upstream side of the outlet. Approaching the dam within hundreds of meters is a shallow, gravelly lake bed that appears to be natural in origin. Without any specific evidence to the contrary, it was assumed that this approach is unmodified from the historical condition.

The flow through the opening of the control structure is also lined with boulders and cobbles. It is unknown if the apron of this flow gate is concrete or just rocks. The downstream side of the control structure is primarily medium to coarse sand, which has a high probability of scouring under high flow events, such as during the initial opening of the flop gates each year. Signs of sediment erosion and deposition are apparent just upstream of East Higgins Lake drive culverts.

During a survey on May 2013 of the water levels along the Cut River (from the outlet to the inlet of Marl Lake) channel bottom elevation measurements were taken using a Trimble mapping grade GPS unit (Figure 1.2.4). A channel bottom elevation measured approximately 30 feet downstream of the control structure was 1152.07 ft, which is assumed to be close to the natural channel bottom, where "natural" is defined as unregulated. Channel elevation was recorded in 1956 for the *Higgins Lake Level Control, Roscommon and Crawford Counties* report of 1151.0 ft, indicating a 1.07 ft discrepancy, which could easily be associated with the location of the measurements. MSU's field crew measured elevations just downstream of the control structure, whereas the location of the Michigan Conservation Departments' measurement is unknown. The deeper channel historically could be a legacy of scour from the high flows experienced during logging years, with subsequent aggradation of the channel bed during more recent lower and stable flow periods. It could also be a legacy of reported dredging of the channel, which has since filled in with sediment.

Figure 1.2.4. Photo of GPS and total station survey set up along the Cut River at the culverts under East Higgins Lake Road.

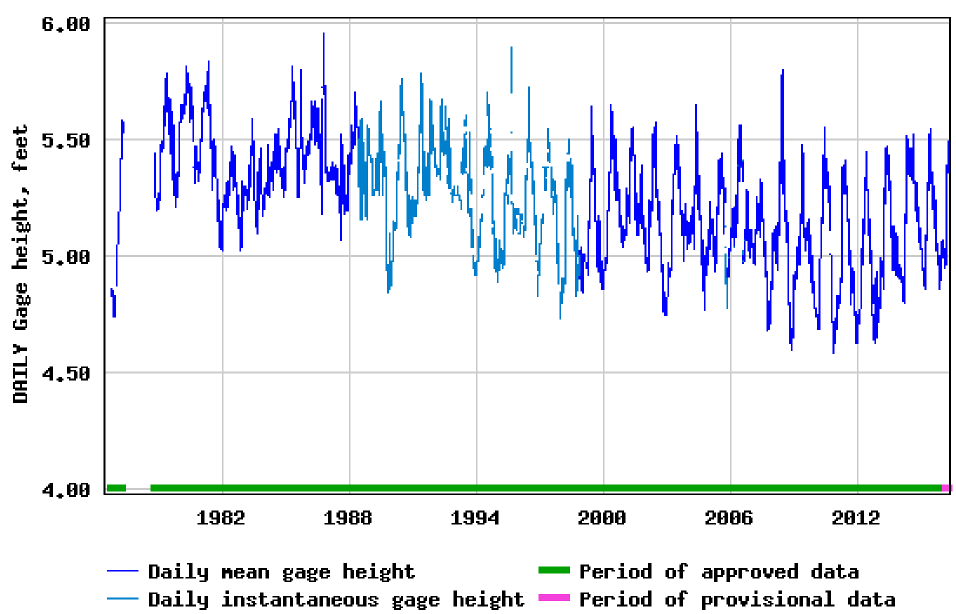
1.3: Historical Lake Levels

The artificial control of the lake began during the lumber boom in the area from mid 1800's to the 1880's. During this period, a dam would be constructed each year, causing water levels to rise 3 to 4 feet to aid in the log runs down the Cut River. After the seasonal transport of the logs down the Cut River, the lake would remain at natural levels for the remainder of the year. After the logging industry left the surrounding area, the lake remained unobstructed until around 1911 when a recreational dam was erected. The new control structure was ambitious and caused enough erosion to have a consensus to remove it within a year after completion.

By 1926 a legal lake level of 1154.11 ft above mean sea level (amsl) was established to a datum provided by Fargo Engineering Co. and confirmed by the Michigan Conservation Department (MCD) in 1956. By 1936 a dam was constructed, but was difficult to operate at the desired level due to the width and height of the stop log gates. The 1941 Fargo report investigated the effects of the legal lake level on the shoreline. The conclusion was that the established lake level of 1926 was acceptable. The 1956 Michigan Conservation Department's report seconded that conclusion of the legal limit of 1154.11 ft amsl. But the same 1956 report also voiced strong concerns that higher water levels would begin to erode the shoreline, since it was already evident as a problem. The state made recommendations to lower the lake during winter and spring to counteract the erosive actions of ice push and spring melts. The 1956 recommendation of the lower winter elevation of 1153.5 ft amsl was to allow for the capture of snow melt and ensure if spring had abnormally high precipitation it would not exceed an elevation of 1154.11 ft. This recommended drawdown was to start by October 1st and the spring recovery was to start when the spring flows/melt had passed. The date on which dam management began its recovering toward the legal level was not mandated, but was an educated decision with practices that varied through time. MCD was very concerned of the inevitable damage to the lakeshore if lake levels were not at or below the legal level. The MCD viewed the legal level similar to a speed limit, not to exceed, but the ability to be lower.

The first USGS gage was installed on Flag Point on September 1, 1942. The zero value of the gage was set to 1148.74 ft AMSL, 1926 datum. The current USGS gage, located in the South Higgins State Park, has been present since October 1, 1976 (Data shown in Figure 1.3.1).

Figure 1.3.1: Graph of lake levels of Higgins Lake from 1976 to 2016 from the USGS gage station, 42805084411001. For reference, the gauge datum is 1148.74 ft, thus on this plot legal summer level is 5.37 feet, and winter levels are 4.62 feet for the 2009-2014 period, and 4.85 feet for all other years.



The original court ruling of 1926, relied on the state law of Inland Lake Levels Act 377 of 1921, and set the lake level at 1154.11 ft. During that period, little thought was made with regards to the flow of the Cut River ecosystem and the possible effects of future development around the lake. During the initial judgment there was no mention of seasonal adjustment. The Inland Lake Level Law, Act 194, Public Acts 1939, provided for establishment of additional levels above or below the legal normal. In 1982, the Circuit Court established a legal winter lake level, not to exceed a decrease of more than 6 inches below the legal summer level, 1153.61 ft amsl.

The most recent adjustment to the legal lake levels were from a 2009 Circuit Court judgement that lowered established winter lake level from 1153.61 ft to 1153.36 amsl for a 5 year period. This trial period expired during spring 2014, without a renewal or extension, thus the current winter legal lake level is maintained at 1153.61 ft amsl until April 1st or ice out, whichever comes first, then raised to the summer level.

1.4: Historical Lake Bathymetry

The bathymetry of Higgins Lake was first fully mapped during the winters of 1936 and 1937. For this effort, the survey crew (part of the Civilian Conservation Corps, or CCC) would wait until the ice was thick enough to support the weight of participants and allow for drilling holes to access the water. Lead lines were employed to reach the lake bottom and from the top of the ice the depth was recorded. The ice surface was surveyed in and used as the reference for elevation. The sample spacing within the shoal area was every 20 ft until the deep basin which then was every 50 ft. A maximum depth of 135 feet was recorded in the northwestern section of the north basin, while a typical shoal depth of less than 10 feet was recorded. Indeed, no data were available on depth variations within this zone, which necessitated Task 2 of this study.

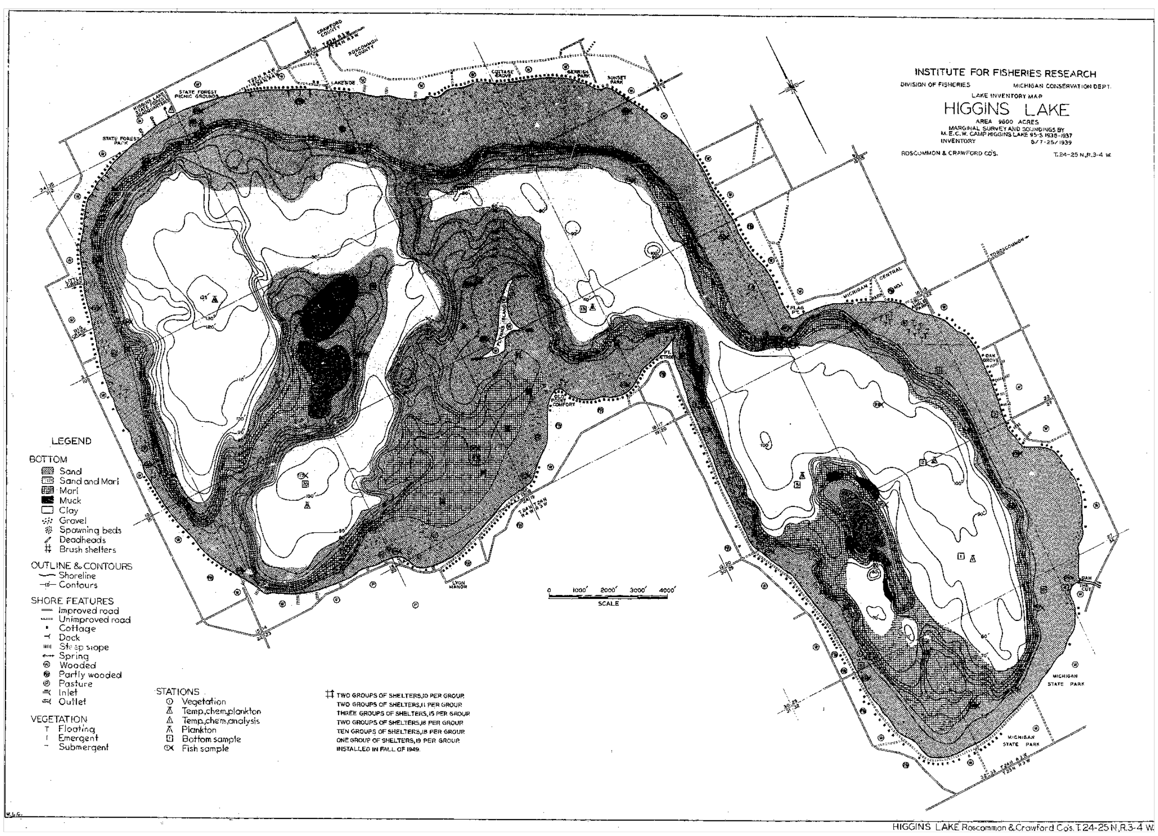


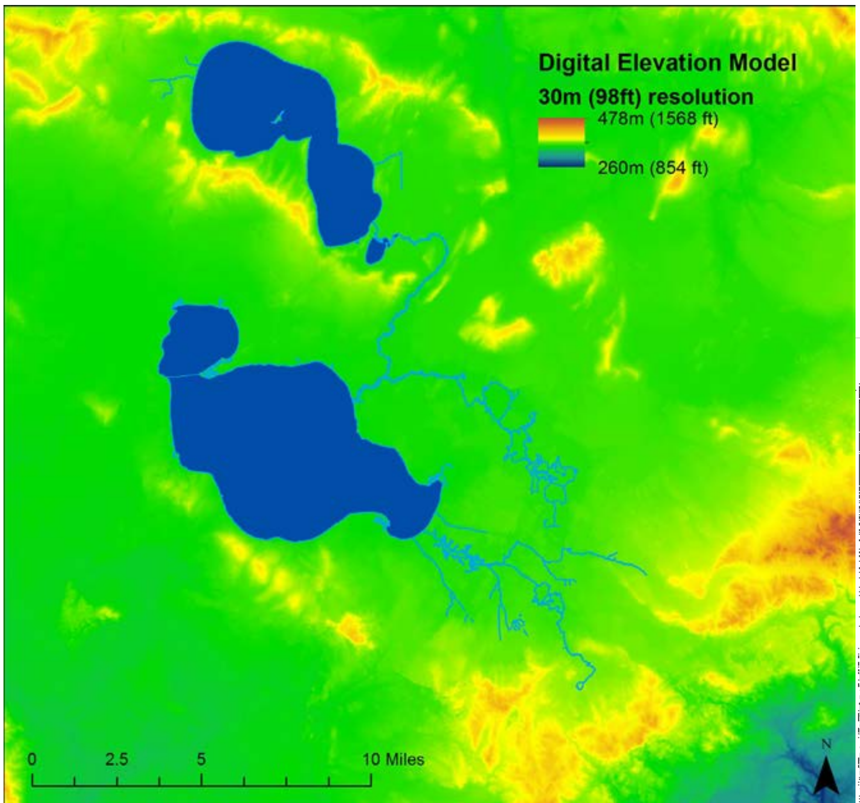
Figure 1.4.1. Original Division of Fisheries, Michigan Conservation Department bathymetric map of Higgins Lake, published in 1939. A higher resolution copy is available online from the Michigan Department of Natural Resources.

1.5: Historical Outlet Position/Depth

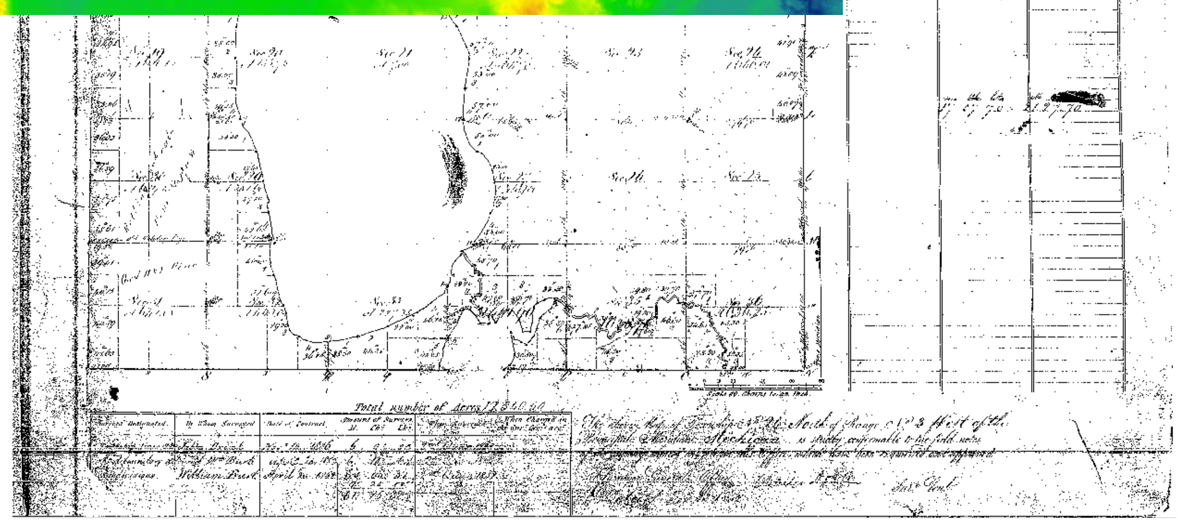
The Cut River was mainly used during the timber boom for the transport of logs; as stated in the *1956 Higgins Lake Level Control, Roscommon and Crawford Counties* report, the river was dredged to allow timbers to freely float to Houghton Lake. Any remnants of dredging during the late 1800's were not observed by MSU and UM field teams while performing the Cut River survey. According to the Public Land Survey Plat map of 1852 (Figure 1.5.1) the outlet has remained relatively in the same position to the present, even with many dam restructuring projects, including the latest in 1995. According to the 1956 report, the stream channel elevation was 1151.0 ft, which is difficult to confirm as the original unaltered channel bottom due to multiple modifications through time. According to correspondence with the Michigan DNR and DEQ in 2015, the agencies provided a letter from The Higgins Lake Property Owners Association, dated 1/3/1952. According to the written testimony of the acting president, Paul H. Bruske, during the 1950 reconstruction of the dam, Roscommon County removed "perhaps 100 tons of rock out of the inlet". The permit for the most recent modification of the lake level control structure in 1995, did not specify a channel bottom elevation at that time. Specification by the Michigan DEQ of the flow through section of the level control structure was to be open to the elevation of the river channel bottom. However, the contractor never supplied an elevation of the channel bottom to the state to allow for comparison of historical elevations.

Figure 1.5.1. Public Land Survey map from 1852, accessed through the Michigan DNR General Land Office Plats Website.

1.6: Surface and Ground Watersheds



Understanding the hydrologic behavior of a system requires information on the influence of the landscape "upstream" of a point. This concept is well established, however the only important watershed of a lake



is generally considered to be the area of the land surface that drains overland to a lake. **Figure 1.6.1**.

Connected hydrologic features from the Higgins, Cut, Backus, Houghton system overlain atop the National Elevation Dataset (NED) 1 arc-second Digital Elevation Model (DEM). This DEM has approximately 100 foot spatial resolution.

Figure 1.6.2. Map of the surface watersheds generated from the 1 arc-second NED DEM of Higgins Lake, the Cut River above the confluence with Backus Creek, Backus Creek and the Cut River below their confluence, and Houghton Lake

For this investigation, we extend this concept to encompass the region of groundwater drainage to the lake, hence the term groundwatershed.

Tools are widely available to calculate the surface watershed of lake, using detailed maps of surface elevations known as Digital Elevation Models (DEMs). Using a DEM, the flow direction of each map point is established, which are then summed to calculate the watershed. Figure 1.6.1 shows the Higgins/Houghton Lake system within a DEM. One can gain an intuitive understanding of watershed dimensions using the DEM alone, but a more detailed calculation can produce some surprises.

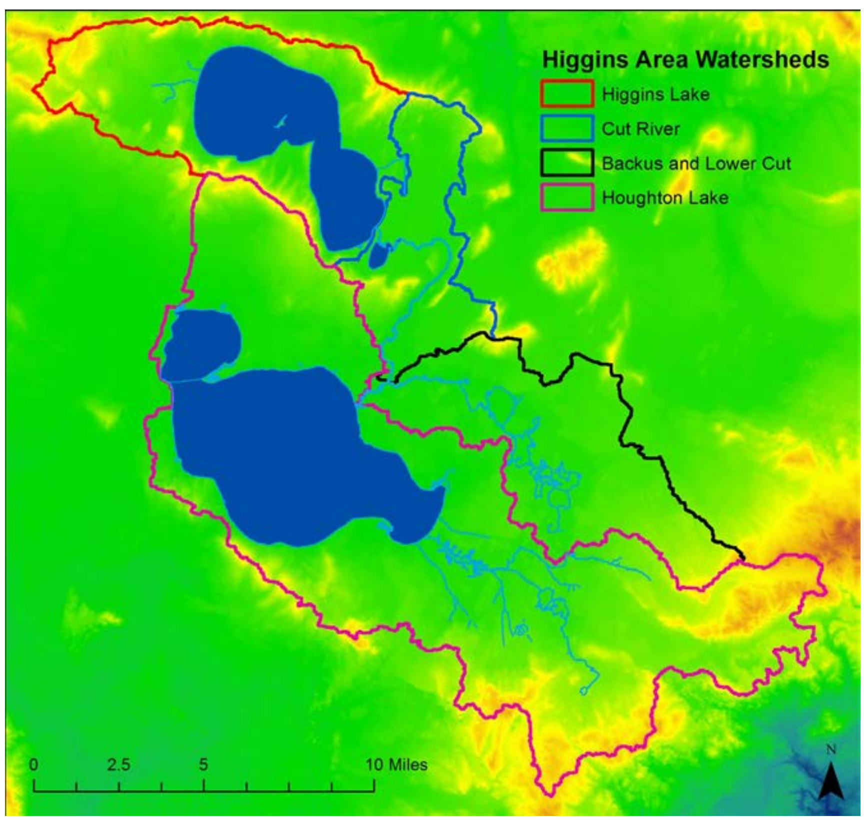


Figure 1.6.2 maps the surface watersheds calculated using the D8 flow direction algorithm in ArcGIS. Note that Higgins Lake has essentially no surface watershed on its southeast edge, proximal to its outlet. Also, the surface watershed areas in this map are somewhat exaggerated due to a simplifying assumption in the D8 flow algorithm. All internally-drained regions are removed prior to watershed calculation. The portion of the Cut River watershed north of the Higgins Lake outlet is actually drained by a wetland that connects only at much higher levels than typically occur in

most years. Thus, in general, the Cut River has a functionally small watershed until its merger with Backus Creek near Houghton Lake.

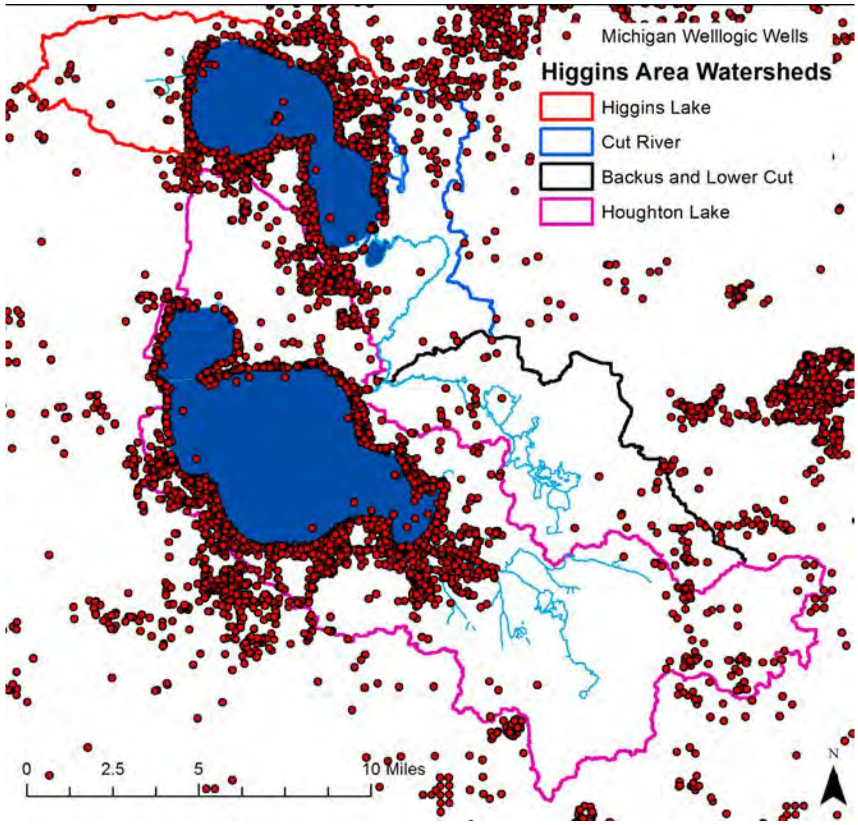


Figure 1.6.3. Map of drinking water wells retrieved from Michigan's Well Logic database for the Higgins Lake Area. Locations of wells are taken directly from database attributes and may contain some errors that are later addressed via filtering.

To map the groundwatershed, which is the source area of groundwater that flows into a water body, an equivalent of the surface DEM is needed: a water table elevation map. This can be obtained either through a groundwater model, or by interpolating a map of water levels using available measurements. The latter approach was selected here, and a database of drinking water wells was downloaded from the State of Michigan. Each of these wells has a measurement of static water level at the time of installation, which varies from the late 1960s to present day. The wells in this region are shown in Figure 1.6.3. There are a approximately 6,400 wells surrounding the lakes in this view of the lakes, and in some of the surrounding developed areas, while fewer are available in the less populated areas surrounding the lakes.

A variety of methods are available to create a map of water levels using these measurements. We chose a method known as Simple Kriging, which is an unbiased linear estimation method that uses the correlation between each measured value and its neighbors as a function of separation distance to produce a weighting map for how strongly each measurement impacts the the value at all other locations. As a first step before kriging, all wells in Michigan were downloaded, over 500,000 in 2015. These were filtered to remove water table estimates that were outside of 3 standard deviations from all others within a 1000 meter radius. This iterative outlier removal was repeated 3 times. These filtered data were then fit to a Stable semi-variogram model in ArcGIS, which produced a map of water tables for the entire Michigan Lower Peninsula. The Higgins/Houghton region of this map is shown in Figure 1.6.4.

Given this interpolated water table map, the D8 flow direction method could then be applied to calculate groundwatersheds for each of the hydrologic systems in the region. Separate groundwatersheds were calculated for Higgins Lake, Cut River, Backus Creek and the Lower Cut, and Houghton Lake. These are overlain on a map with the surface watersheds to show how the two systems differ. Note that Higgins Lake has a groundwatershed that is roughly 89% larger than its surface watershed. Given the significant northwestern extent of the groundwatershed, we would expect this portion of the lake to be a strongly groundwater gaining section. In contrast, the southeast portion of the lake has essentially no groundwatershed, thus we would expect this area to be a location of groundwater loss from the lake. This may be a region where groundwater loss feeds wetlands to the east of the lake.

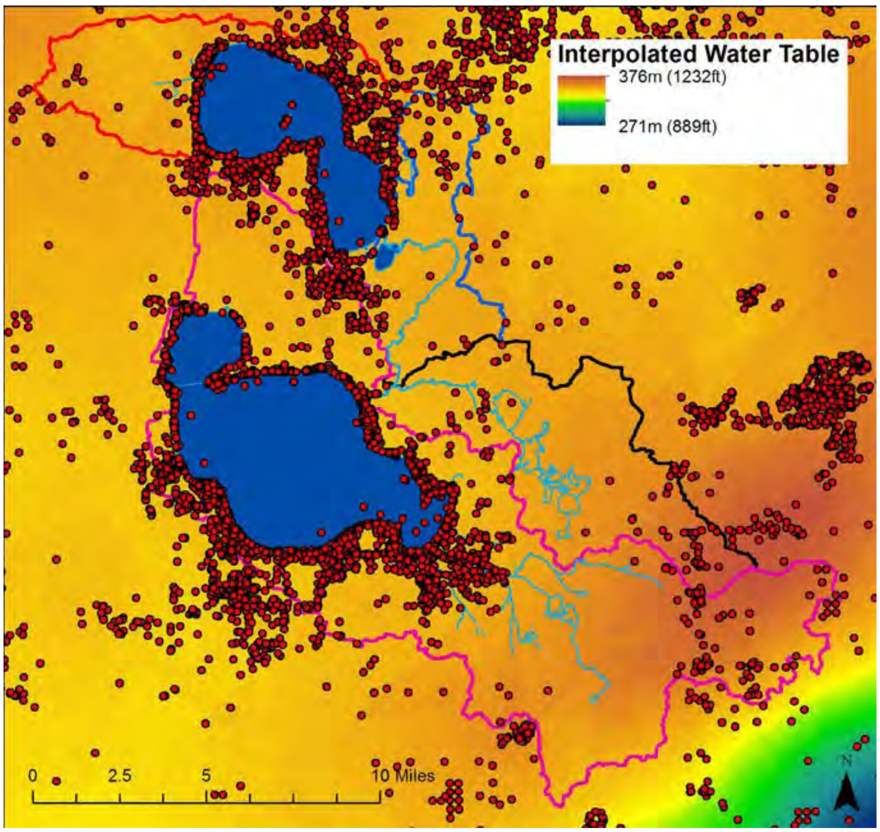


Figure 1.6.4. Map of interpolated water table elevations created using kriging.

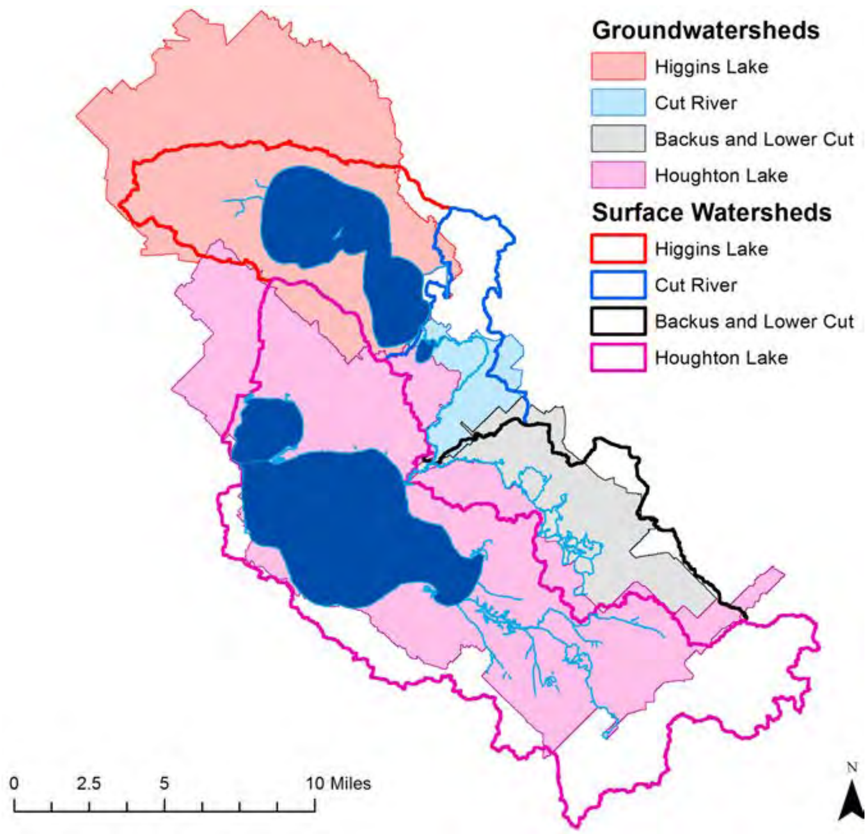


Figure 1.6.5. Map of groundwatersheds and surface watersheds for Higgins Lake, Cut River above the confluence with Backus Creek, Backus Creek and the Lower Cut River, and Houghton Lake. Note that there are large discrepancies between surface watershed and groundwatershed divides.

Another important observation from the groundwatershed and surface watersheds are that the upper Cut River has essentially no groundwatershed, and no functionally significant surface watershed. Thus we would expect that surface water inputs from Higgins Lake would dominate Cut River flows in the upper portion. Note too that Marl Lake is split down the middle in terms of its groundwatershed, where the eastern section of the lake is fed by groundwater while the western section likely loses groundwater toward Houghton Lake to the southwest.

1.7: Historical Weather and Climate Data

Hydrologic systems exist in dynamic balance with their landscape and the weather that ultimately drives the movement of water within them. To better understand the trajectories of the Higgins Lake region, we downloaded historical air temperature and precipitation data from NOAA's Global Historical Climatological Network (GHCN), which is a network of co-operative gauges maintained for at least 100 years. Precipitation shows little trend through time (Figure 1.7.1). On average, there is approximately 30 inches of precipitation per year, with a minimum near 20 inches and a maximum near 40 inches.

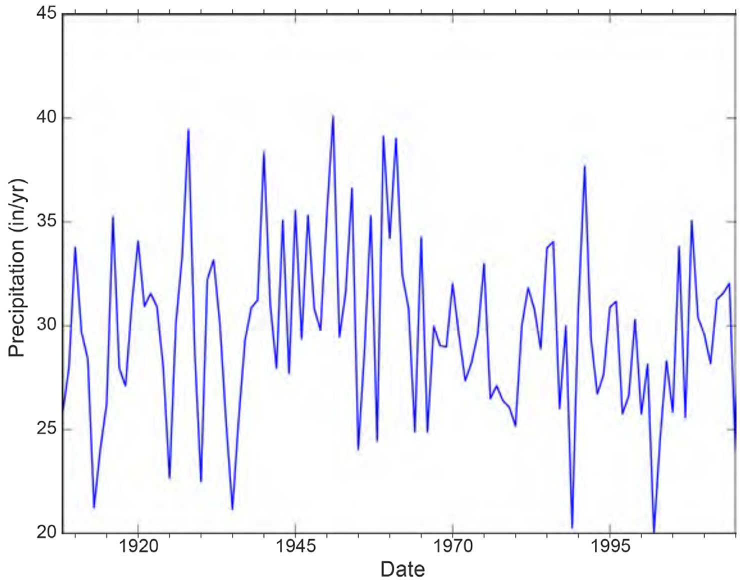


Figure 1.7.1. Plot of historical annual precipitation data from NOAA weather stations in Roscommon county, from 1908 to 2015. There is no significant trend in this dataset.

In contrast, average annual temperatures (Figure 1.7.2) show a strong warming trend over the last 108 years of record. Temperatures at the turn of the 20th century averaged approximately 42 degrees F, while the last decade has seen temperatures closer to 44 degrees. A linear trendline fit to these data has a slope = 0.25 degrees F/decade (significant at p<1%). These temperature trends are consistent with regional trends across the Great Lakes Basin during the same period.

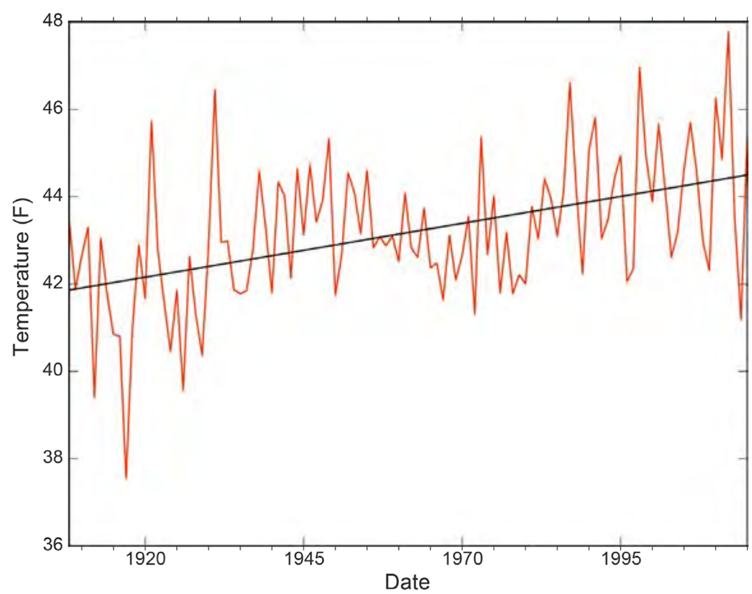


Figure 1.7.2. Plot of historical daily average temperatures from NOAA weather stations in Roscommon county, from 1908 to 2015. A linear trendline is plotted in black.

Our period of investigation will focus on the latest 15 years of this period, but these longer term trends are shown to provide context for how systems behave within a longer time period.

1.8: Aerial Photo Synthesis, Shoreline and Cut River Channel Analysis

A significant effort was made to use historical aerial imagery to quantify changes in shoreline and Cut River position through time. Michigan has collected aerial imagery roughly each decade across the entire state since 1938; these photos are archived at Michigan State University.

The oldest view of the Higgins Lake region is provided by General Land Office surveys from the the 1850s. These maps were scanned and georeferenced (points on the map related to known points on the land surface, typically section lines that match current roads and intersections) and overlain on modern maps of the lake. Clearly, the lake is roughly the same dimension now as it was over 150 years ago (Figure 1.8.1). In particular, the shallow shelf that characterizes much of Higgins Lake recreation and shoreline concerns is not a product of human intervention, but is clearly a natural occurrence.

Figure 1.8.1. The original Higgins Lake survey from the Michigan public land survey plat maps from the mid 1800's. The plat map was georectified using aerial imagery underlay, provided by the USDA, taken on August 31 and September 1, 2012.

Each aerial imagery series consisted of multiple photos, which were scanned, contrast adjusted, georeferenced, and then mosaiced to produce a single image. Figure 1.8.2 shows the outcome of this process for the 1938 aerial imagery series.

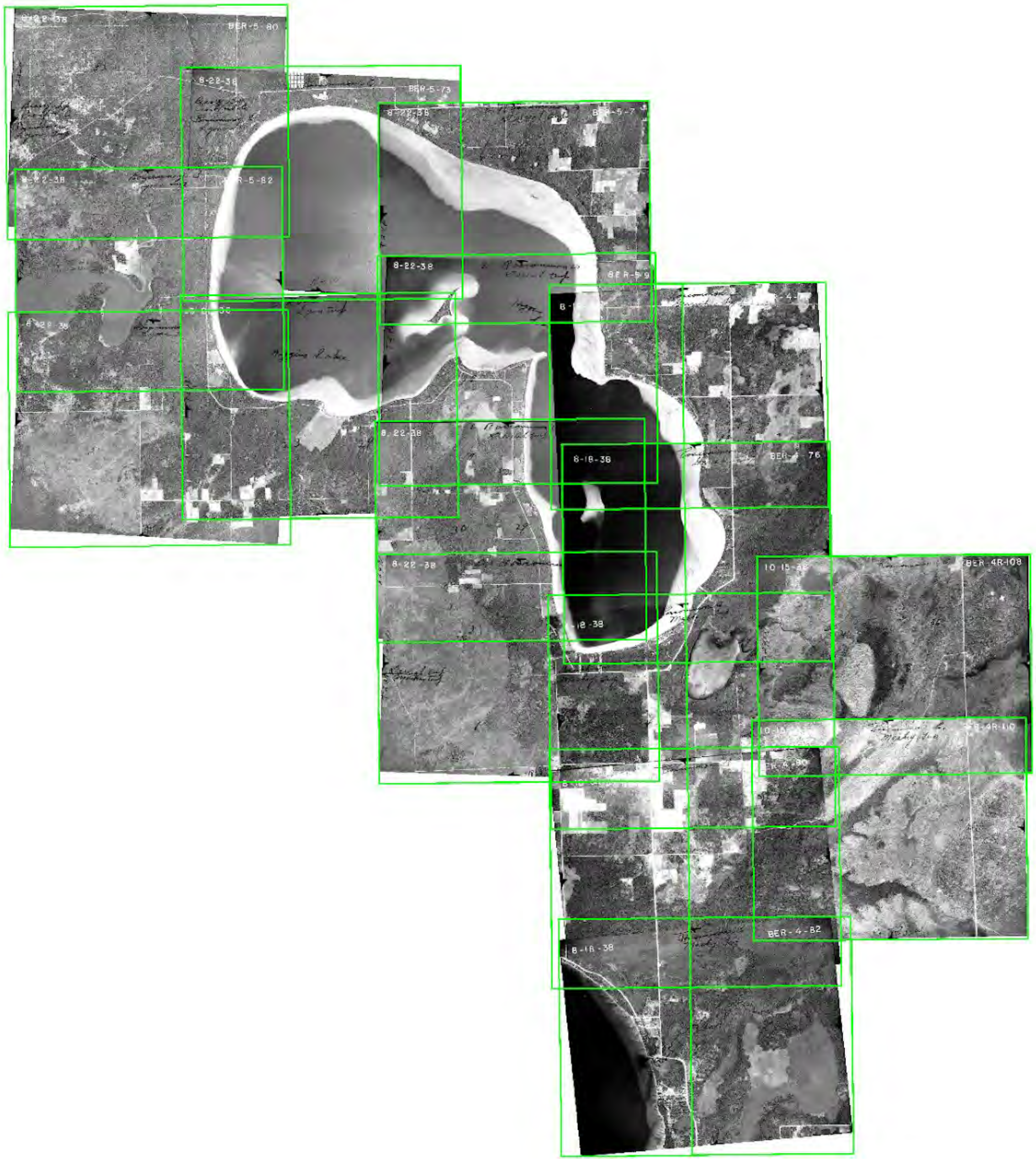
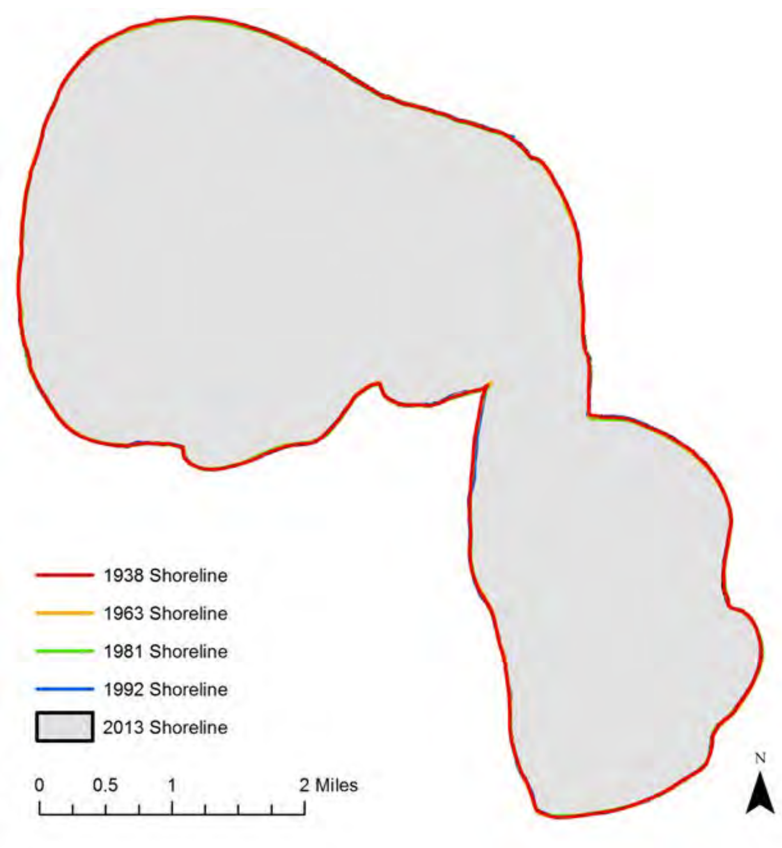


Figure 1.8.2. Mosaiced historical aerial imagery (1938) showing the separate images, with green outlines for each image.

Other series included 1952/1953 (incomplete), 1963, 1981, and 1992. High resolution satellite imagery is then readily available starting in the mid 2000s.

Using those aerial images, the shoreline of Higgins Lake was manually traced for each series (Figure 1.8.3). Note that at the large scale, very few changes are visible in the shoreline position. However, some areas across the lake have been consistently receding (eroding) shorelines through time, as visible in zoomed in portions of the region. For instance, Figure 1.8.4 shows a section of the northern part of the north basin of the lake. With the exception of the 1981 series (which has position errors across the lake) there is a consistent trend of erosion visible.

Figure 1.8.3. Map of shorelines manually digitized from historical aerial imagery. Note very few differences in shoreline position are notable at this scale.



To more systematically examine whether the imagery series provide evidence of shoreline change, a series of lines perpendicular to the shoreline were overlain along the perimeter of the lake. Intersecting these lines with the historical shorelines provided a direct measurement of shoreline change at each line (which were located 250 meters, 820 feet, apart). For each line, a linear regression of change relatively to the 2013 position was calculated, and used to quantify shoreline erosion rates. However, uncertainties in the imagery locations are significant enough that this information should be used as qualitative evidence for shoreline change rather than accurate estimates of erosion rates.

The uncertainty in location of the georeferencing position was assumed to be ~30 feet (10 meters). Then, total change in shoreline position since 1938 greater than 30 feet was assumed to provide evidence of significant erosion occurring, while rates between 0 and 10 were viewed as being evidence of low to moderate erosion, while shoreline erosion values of less than 0 (which would be migration of shoreline into the lake, which is likely not occurring on a broad scale) were assumed to have low likelihood of erosion. These were then mapped as Figure 1.8.5.

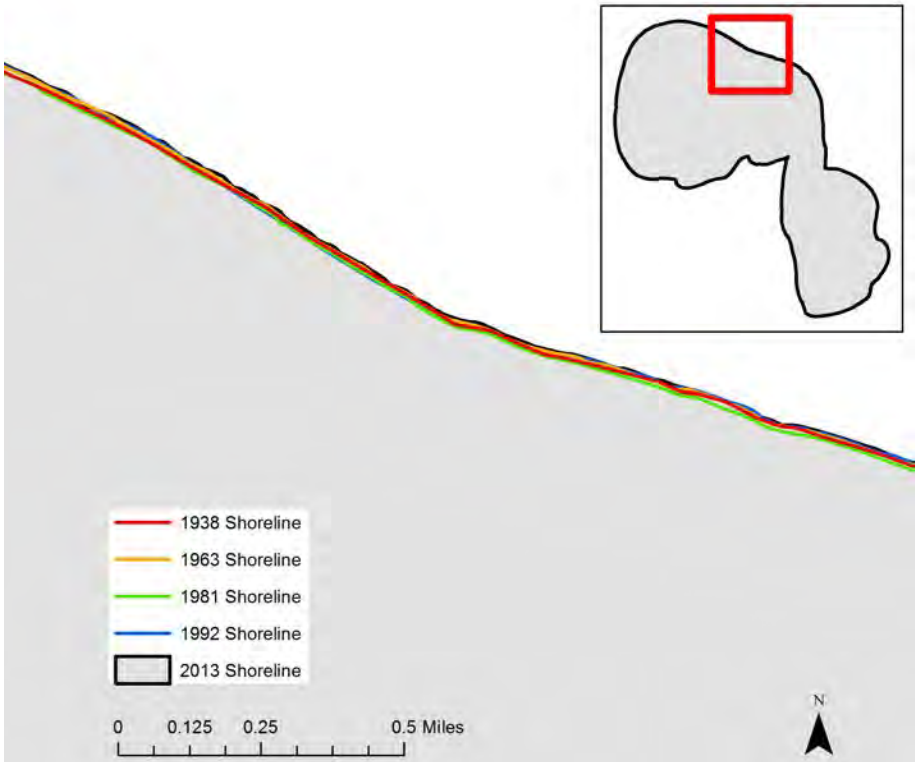


Figure 1.8.4. Zoomed map of a portion of the northeastern Higgins Lake Basin showing trends in shoreline position. An exception is the 1981 shoreline, which appears to be relatively offset across much of the lake area.

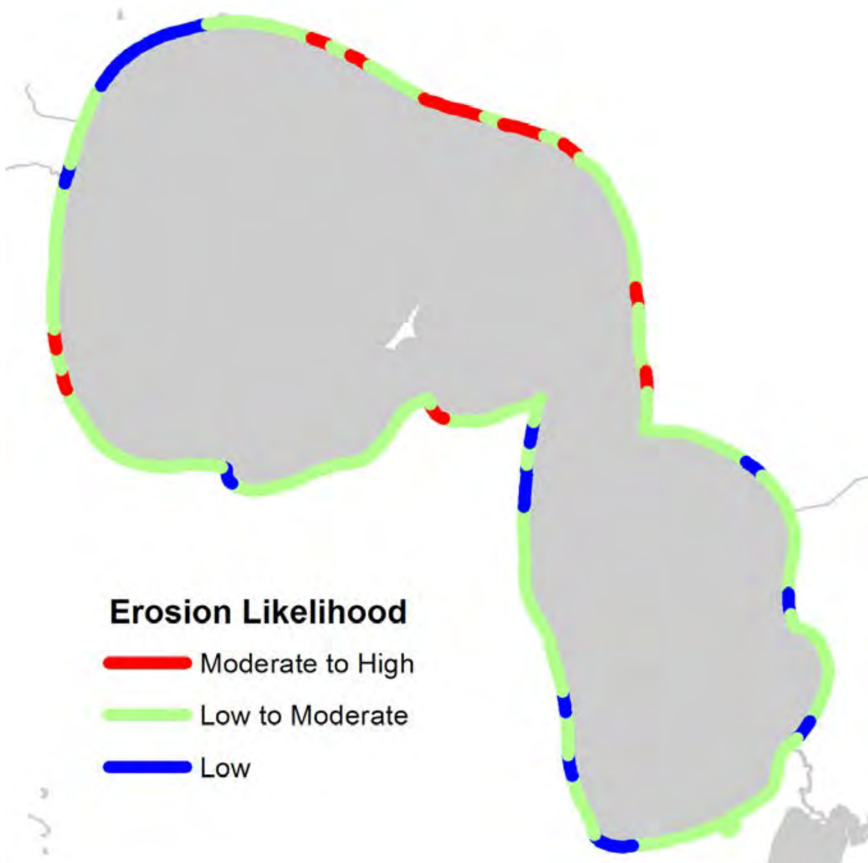


Figure 1.8.5. Figure of the erosion likelihood, mapped using thresholds of uncertainty established by georeferencing the historical aerial imagery.

Evidence of moderate to high erosion rates are present in four sections of Higgins Lake, on the eastern and northern sections of the North basin, the lower western section of the North basin, and a small strip of the southern portion of the North basin. Evidence of low to moderate erosion is present across much of the rest of the North basin, except for the northwestern portion where shorelines appear stable. The South basin also appears to have more stable shorelines.

Changes in the position of the Cut River channel were also mapped through time. These images were more problematic to georeference due to the relative lack of roads adjacent to the river. Thus, position uncertainties are relatively high, but shape of channel within a series is robust. Figure 1.8.6 shows the five time series overlain with few changes visible at this scale (with a few exceptions).

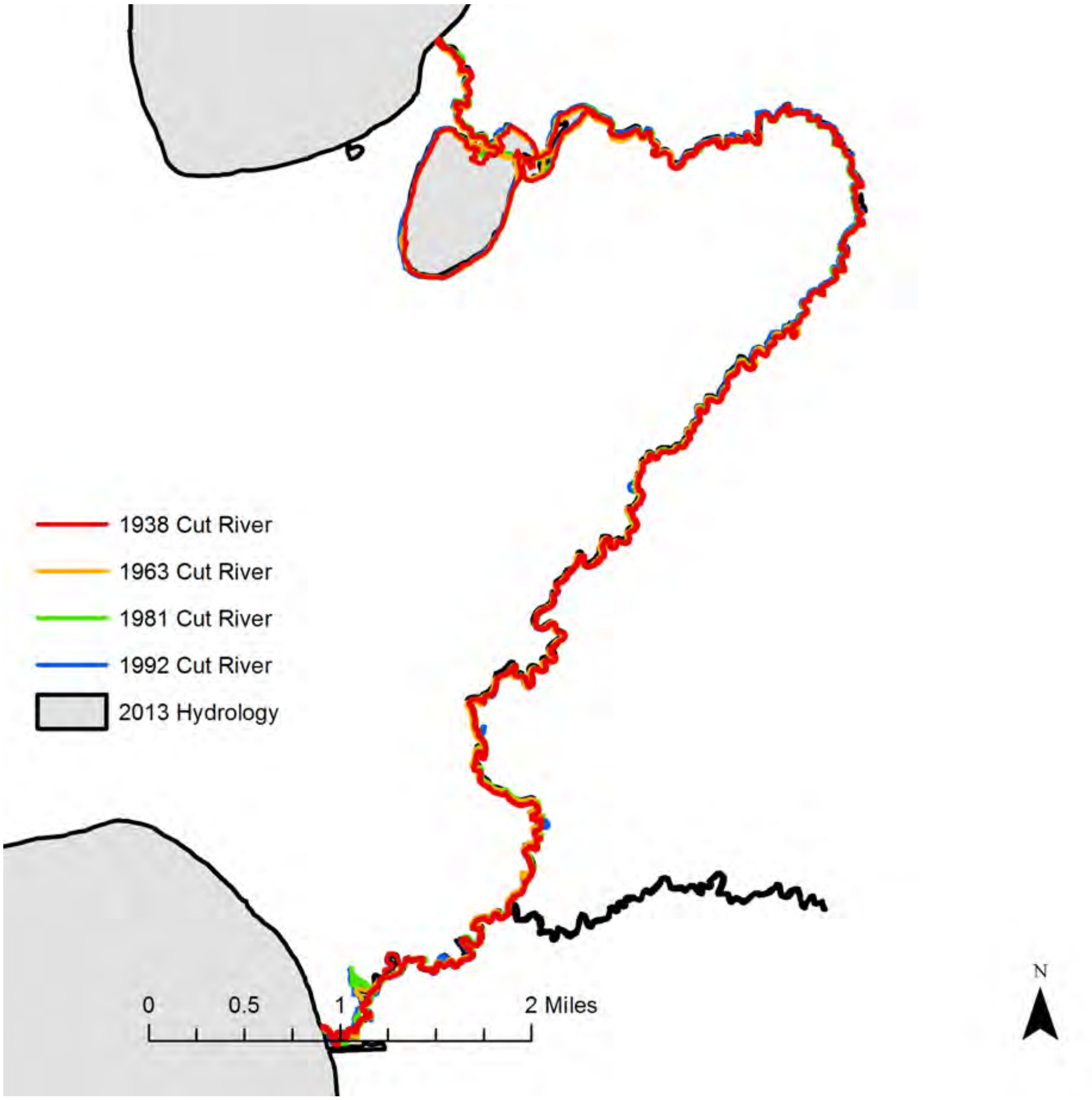
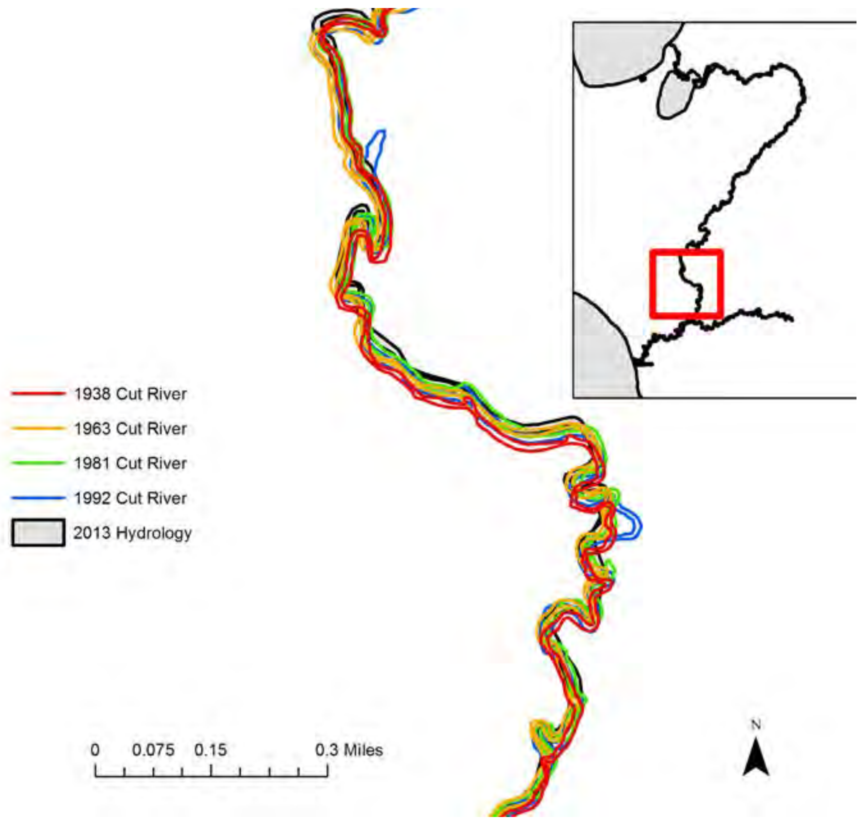


Figure 1.8.6. Map of Cut River stream banks manually delineated from digitized aerial imagery. Note few changes are visible at this scale.

Figure 1.8.7 provides a zoomed in view of a section of the lower Cut River above Backus Creek that shows some interesting changes in the meandering course of the channel, with changes visible on the roughly decadal scale intervals between these aerial imagery series. It is clearly an actively meandering channel, but has changed little in its bulk course since 1938.

Figure 1.8.7. Zoomed map of one section of the Cut River showing observable changes among the aerial imagery series. Note, general parallel shifts in channel position are related to inaccuracies in georeferencing, not channel shifts. Changes including production of new meanders and cut-offs, visible in the lower half of the zoomed channel, are genuine changes in Cut River morphology.



1.9: Lake Level Scenarios to Be Considered

The hydrological and ecological teams came together to establish a series of lake level change scenarios that would allow for a wide range of issues to be investigated such as fishery habitat loss or increase; vegetation loss or increase; shoreline position change; as well as the effects of groundwater elevation. The lake elevations that were used to investigate the ecological and hydrological effects on the lake and its surrounding environment include: 1154.11 ft amsl (legal summer level), 1153.61 ft amsl (legal winter level), 1153.78 ft amsl (4 inch lowering), 1153.36 ft amsl (9 inch lowering), 1153.027 ft amsl (13 inch lowering), 1152.61 ft amsl (18 inch lowering), 1152.443 ft amsl (20 inch lowering). The decrease of 18 inch and 20 inch in lake level is an assumed maximum reduction if the lake level control structure were to be permanently opened or removed respectively. Initially, the 6 inch drop scenario was assumed to be the smallest change that would be considered, however following analysis of Task 5.4 we added a scenario with a 4 inch lowering of lake level due to the lower than expected simulated lake level declines.

Task 1 Findings Summarized

- No evidence of different outlet position in recorded history
- No evidence of significantly deeper outlet or within-lake approach historically
- Little change in bulk position of shorelines over time: lake area largely unchanged
- Evidence of significant shoreline erosion in some regions, particularly the NE and W quadrants of the North basin.

- Lake level scenarios between 4 and 20 inch drop defined for further analysis in Tasks 2, 5, and 6 (separately reported).

Task 2: Bathymetric and Shoreline Surveys

This Task encompasses data collection efforts on Higgins Lake during the summers of 2012 and 2013. These included collection of both depth data and photos for characterizing shoreline character (i.e. armored, not-armored) as well as a comprehensive count of numbers of docks on the lake.

2.1: Shoreline Character and Docks Survey

During the shoreline bathymetric surveys, described in Task 2.2, an extensive photographic survey was conducted. These photos were taken with a GPS-integrated digital camera following standard procedures: 1) take the photo while facing directly toward the shoreline, so that the GPS location can be readily mapped to the shoreline location, 2) take a photo of each transition of shoreline character, 3) take a single photo for each dock, even if multiple docks are in the same field of view. In total, over 2,000 photographs were taken providing a thorough inventory of both docks and shoreline character. The docks dataset is described below in Task 2.2.

Even though the camera included a internal GPS, the accuracy was only to within 10 meters. However, by matching the timestamp of the photographs allowed a more accurate differential GPS unit on the Acoustic Doppler Current Profiler (ADCP, described below) being used for bathymetric data collection, the GPS coordinates to be updated to an accuracy of +/- 1 meter. Using the georeferenced images the research team was able to manually classify shoreline characteristics as armored, natural vegetation/beach, or cobble riprap. From these classified images, a total percentage of armored shoreline was calculated for each 250 meter (820 foot) section of shoreline (FIgure 2.1.1).

The presence of shoreline armoring is likely indicative of past erosive activity, which is supported by the fact that the areas of the lake with the highest percentages of armoring have less likelihood of active erosion (Figure 1.8.5). In particular, the western edge of the South basin shows this inverse relationship. Another potential explanation for this relationship is that the addition of seawalls to areas that are not otherwise needed may actually result in unintentional erosion of adjacent property owners as wave energy is concentrated at the edges of the armoring. This may therefore cause the perceived necessity of armoring to propagate along the shore.

A literature review published by the U.S. Army Corps of Engineers titled *The Effects of Seawalls on the Beach*, (Kraus, N., 1988) underscores the complexity of shore armouring. Below is a summary of four different questions Kraus asked and answered in their review:

- *What is the maximum scour depth at a seawall?* The depth of scour is dependent on the occurrence of waves, wave duration, the reflectivity of the wall, and the initial beach morphology. In general wave height within deep water appears to be a good estimate. However, scour depth is decreased if the reflection coefficient of the seawall is reduced.
- *Is the amount of sand scoured equal to the amount eroded across the adjacent beaches without structures?* The volume of material scoured at a seawalls have similar magnitudes and variations as the volume of the adjacent non-armored shores, but the data is highly variable due to

nearshore beach morphology and offshore bathymetry which affects the attenuation of wave energy.

- *Do seawalls accelerate or enhance erosion?* Ways that a seawall can enhance erosion to adjacent non-armored shore are by acting as a groin on the updrift side and impounding sand and causing the waves to flank the sides. Other erosive properties of seawalls include an increase in turbulence from wave reflection and enhancement of transport by short crested wave systems from reflected waves.
- *Is it beneficial to design seawalls to be "softer"?* Studies have concluded that slanting permeable seawalls have smaller reflecting coefficients and suffer less local scour than vertical or near vertical walls. These softer structures appear to mitigate local scour and allowed the beach to respond in a similar way as natural beaches.

The photo database collected for this project provides a baseline assessment to examine future changes in shoreline condition. This provides a valuable resource to organizations working to improve the reflection coefficients of existing armoring, and provides for best practices in the event of newly installed seawalls.

Another potential future use of this data would be to assess the impacts of shoreline armoring on property values. Indeed, studies have shown that armoring can have a negative effect of property values for the entire lake community including the non-waterfront property owners (Kriesel and Friedman, 2003). Kriesel and Friedman find that at first, the few individual waterfront owners that install shore stabilization have a substantial initial increase in property value. However, as more waterfront property owners install seawall stabilization the values drop to original levels. The study also concludes that if erosion of the shore is left unabated, the non-waterfront property has the potential to lose 23% of the value. But this same study also concluded that if the shore is primarily armored this also leads to an overall decrease of property values and a decrease in public use of the lake.

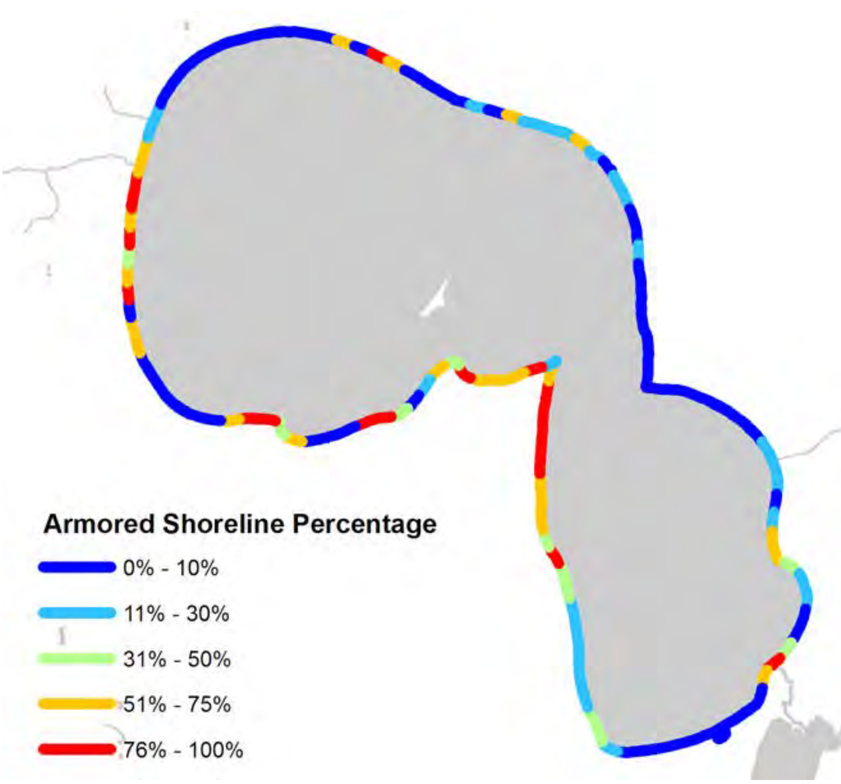


Figure 2.1.1. Map of shoreline armoring percentage averaged

within 250 m (820 ft) sections of shoreline.

2.2: Bathymetric Survey

One of the primary products of this project is a new near-shore bathymetric survey conducted primarily within the first 10 feet of lake depth. As noted in Task 1.4 above, this section of the lake has no further bathymetric detail provided by the 1930s map, yet is the portion of the lake most sensitive to changes in lake level, due to either natural fluctuations or changes in dam management.

Additionally, for the purposes of the ecological assessment conducted for Task 6, a new deep basin and drop-off (the region between the shallow shelf and the deep basin) bathymetric survey was needed. As part of this survey, new instruments would provide not just depth but sediment characteristics (sand, gravel, or soft sediment).

To conduct a near-shore bathymetric survey with accuracy within the first two feet of lake depth, several novel methods were applied: 1) multiple lake level transducers would be installed around the perimeter of the lake to capture bulk fluctuations in lake elevation due to wind-driven seche, 2) a new very high frequency depth sounder would be used that can accurately obtain depth measurements down to approximately 20 centimeters, and 3) a filtering method would be used to remove the effect of waves from the dataset.

As a final product, the near-shore survey and the deeper survey would then be stitched together. This required applying a novel interpolation scheme that captures the unique structures of each of the three lake bathymetric regions: the shallow shelf, the drop-off, and the deep basins.

Spatial Lake Level Analysis

Figure 2.2.1. Photo of water level logger installation.

The MSU field crew, assisted by the UofM field crew installed 6 pressure transducers (FIgure 2.2.1) around the perimeter of the lake shore, at locations shown in Figure 2.2.2. The crews chose to place the transducers onto dock posts to allow easy access and minimal disturbance. At each location the crews used a Trimble GPS to measure the water level for a starting reference of the pressure data. The transducers recorded pressure in millimeters, which relates to the height of water above the unit. The water elevation from the locations were to be used to investigate the lake’s surface relief from the north basin to the outlet.

The data was also collected to link the 6 regions to the bathymetric survey based on their spatial relationship.

These transducers recorded lake level data every 3 minutes for the duration of the bathymetric survey, approximately 4 days. We assessed the data from this deployment and determined that: 1) our data collection took place primarily during periods of relatively calm water, where no significant differences in levels between the gauges were observed, and 2) the accuracy of vertical positioning was not sufficient to determine if wind-driven seche was present during times of rougher water. Although two of the transducers failed to record data, these failures did not affect our overall task of linking lake elevation to the new bathymetric data. The USGS lake elevation gage located at the South Higgins State park records elevation every 15 minutes, which proved to be sufficient to link the depths recorded during the bathymetric surveys to actual water level elevations.

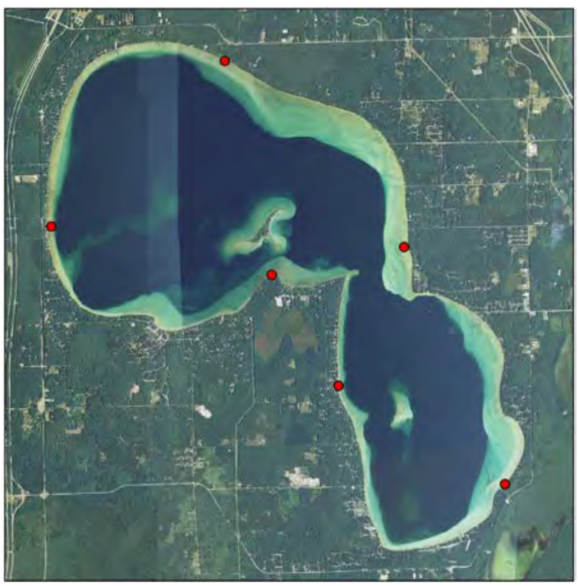


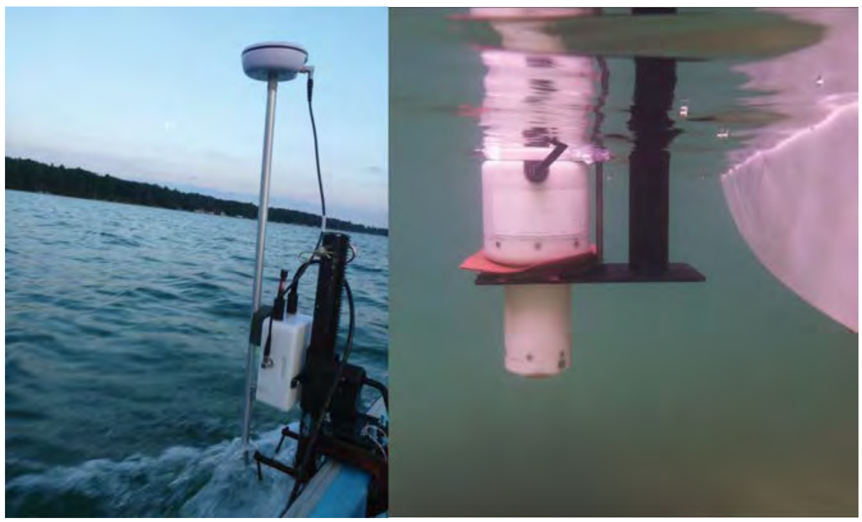
Figure 2.2.2. Map of water level loggers deployed around the lake.

Shallow Bathymetric Survey Methods

The shallow bathymetric survey was conducted using a Sontek S5 RiverSurveyor Acoustic Doppler Current Profiler (ADCP), a device that records depth, current velocities beneath the instrument, velocity relative to the lake bed, and with an integrated GPS provides either 1-meter accurate GPS, or optionally a 1-cm accurate GPS with the deployment of a secondary base station. All data were logged on the instrument at a rate of 1/second (1 Hz). The ADCP was mounted on a custom designed boat mount fabricated by the MSU Physics Machine Shop (Figure 2.2.3). The mount was capable of lowering and raising to best position the ADCP within the water column but with minimal drag. This allows for greater boat speeds, increasing the overall rate of data collection.

Figure 2.2.3. Image of MSU's boat deployment of Sontek RiverSurveyor S5 ADCP with an integrated differential GPS . The image on the left shows the instrument during data collection. The photo on the right shows an underwater view of the instrument while at rest. When the boat was in motion the instrument rose further up in the water.

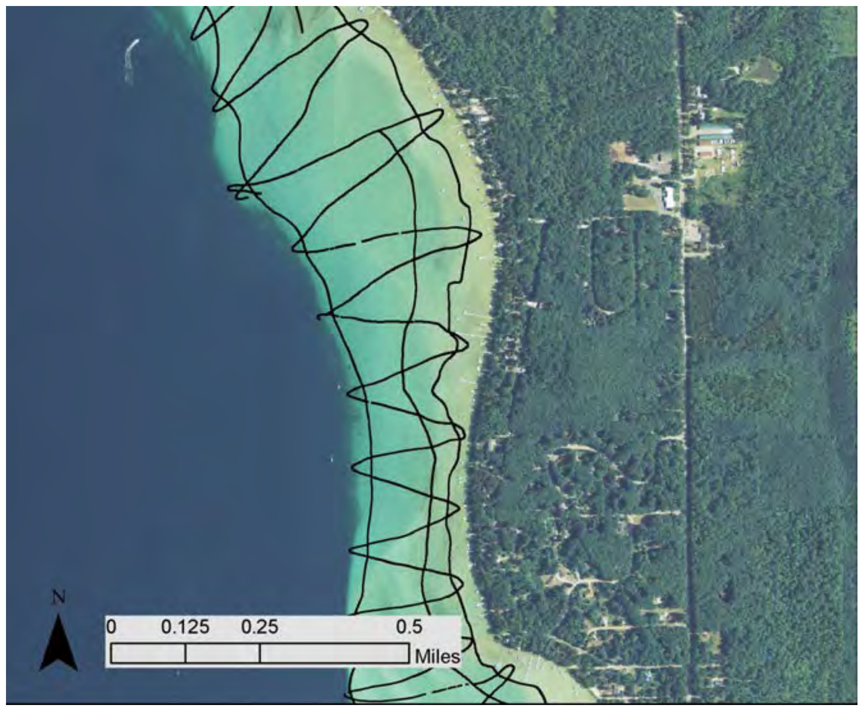
The ADCP was attached to the starboard (left) side of a 14 foot tri-hull Boston Whaler. During the 2012 survey, MSU's average boat speed during data collection was approximately 4.5 mph (3.9 knots). The following year, MSU's field crew used kayaks towing the ADCP on a small foam boat to measure near shore depths as shallow as 7 inches. This single kayak survey involved involved close to 7 days of field effort.



We designed a custom survey pattern to efficiently cover the shallow shelf area. This "warp and weft" pattern included four survey lines, 3 roughly parallel warp transects followed the 0.5, 1.5, and 3 meter depths contours, and a 4th zig-zag weft line to provide greater detail about the depth variation across contours (Figure 2.2.4). The presence of docks and the draft of the boat limited the shallowest line in some cases. In addition to the main shoreline, the central island, known as "Treasure Island" in the North basin and the submerged island within the southern basin were surveyed. Real time depths were referenced by the use a transom mounted Garmin Fish Finder. The fishfinder was also used to navigate our route during data collection. A fifth survey line was added in 2013 for the kayak traverse, with the goal of recording the shallowest depths the instrument could record around the entire perimeter of the lake. This was conducted during summer, thus additional depth data were collected as the kayak was forced to trace an outline of essentially each dock around the lake.

Figure 2.2.4. The warp and weft pattern employed for shoal allowed for optimal data collection.

Following data collection, the data were filtered using two methods: 1) all depth data values of 0 were rejected, and 2) a spectral low-pass filter (Butterworth filter) was designed to remove the effects of waves and boat pitch from the depth data. This spectral filter successfully removed the high-frequency "noise" and produced a clean series of depth along the boat track. The filter parameters were carefully tuned such that peak depths were not excessively smoothed (Figure 2.2.5).



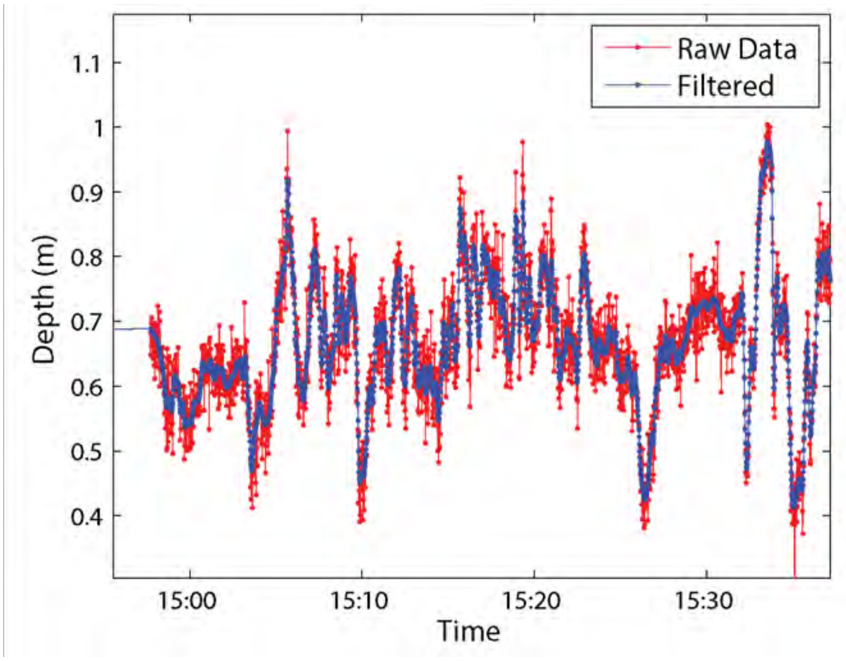


Figure 2.2.5. Raw and spectral-filtered bathymetric data.

Deep Basin Bathymetric Survey Methods

The UM personnel performed the off shore deep basin (>3 meter) data collection using multiple instruments including a Navitronic's Lowrance HDS-8 sonar unit with an integrated WAAS enabled GPS, a Imagenex Yellowfin tow behind side scan sonar. The survey patterned was conducted within a typical survey grid spacing of 400 meters. The average speed for the deep basin data collection was approximately 4 mph. Further details are provided about this survey in the Addendum report for Task 6.

Interpolation of Whole-Lake Bathymetry

When both groups completed their portion of the data collection there was a total of more than 779,000 depth points. But before the two data sets could be merged, the groups needed to first process the data in a similar way. MSU's data were spectrally-filtered as described above, while the UofM team did not need to use these methods as the depths recorded were significantly greater than the high frequency noise due to waves or other noise sources during data collection. The merged depth dataset, which contained roughly 642,000 points after rejecting 0 depth data and merging duplicated depth data, were transformed to bottom elevations adjusted to the varying lake levels by using the 15 minute sampling interval USGS gauge.

During the initial data collection MSU and UofM each survey overlapped in a zigzag pattern along the 3 meter depth shoal-slope zone. This was an integral step to perform a quality assurance and quality control of the separate data sets. The merged dataset was imported into ArcGIS ArcMap (Figure 2.2.6) to begin the interpolation.

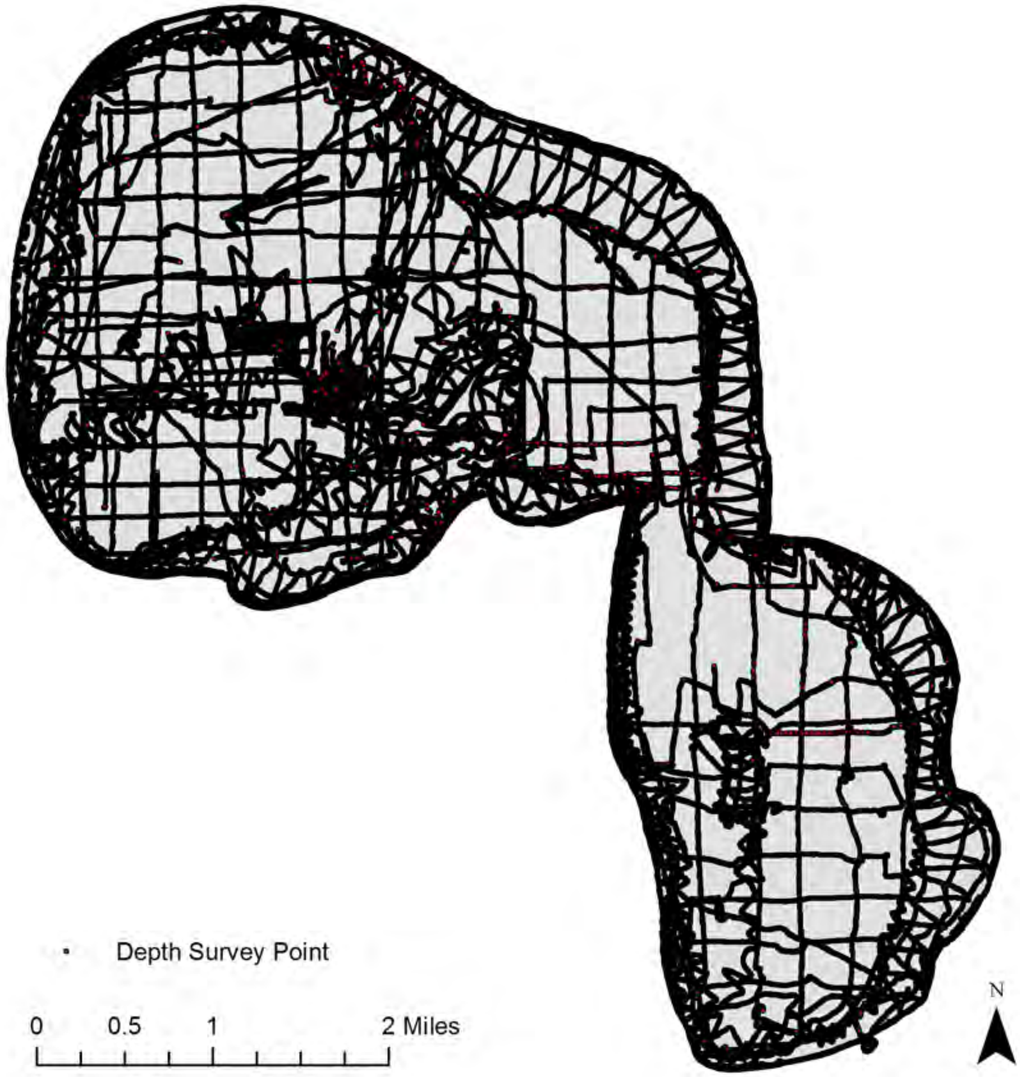


Figure 2.2.6. Map of all points included in the interpolation, a total of 642,902 points remained after quality control was completed.

Interpolation Techniques

Due to the complex nature of the Higgins Lake bathymetry, interpolating three data across all three lake zones proved exceptionally difficult. Methods that smoothly interpolated the deep basin with the drop off tended to underpredict shallow shelf depths, for instance, this is known as the Gibbs phenomenon. MSU researchers tested methods including: Spline, IDW, Kriging and finally Zonal Kriging.

- Spline interpolation works by estimating grid cells values by fitting a minimum curvature line through each of the data points. Spline interpolation works best when the data does not include extreme geomorphological features and the data set is relatively small.

- Inverse distance weighting, known as IDW, interpolates by averaging the data values of nearby points. The closer the neighboring data point is to the estimated cell, the more weight it is given. IDW is usually more appropriate when large sets of data that does not include steep drop offs and the data set is known to represent maximum and minimum values. This method will average the data to create an overall smooth surface.
- Kriging is similar to IDW, as it forms weights from the surrounding data values to predict the unmeasured locations. Unlike IDW, kriging weights are derived from a semivariogram as described above in Task 1.6 that takes into consideration the spatial structure of the data. Predictions are made based upon the semivariogram and the arrangement of the nearby measured values.
- Zonal Kriging is an adaptation of Kriging that allows for separate interpolation within distinct zones, in this case depth bands that defined the shallow shelf, drop-off, and deep basin. Then, the three zones need to be merged in a way that preserves continuity across the boundaries.

A literature review of zonal kriging methods resulted in a range of guidance in terms of how to construct the zones, and in particular how to handle the region where the zones come in contact. To define the zones, we analyzed the depth data to determine the locations where slopes became significantly different. In particular, the drop-off zone is characterized by very steep slopes, whereas the shallow shelf is quite flat, and the deep basin in between. Cutoff depths were determined from this analysis, and are shown in Figure 2.2.7. A preliminary whole-lake kriged map was constructed to define the depths of the zones, while depth values were used to subselect data that would be included in each zonal krig.

To handle the overlap region, we created a weighting map that is then multiplied by each zonal kriging estimate. This weighting map smoothly interpolates between each zone krig map. The width of the overlap zone was adjusted to minimize the difference between the observed values and the interpolated values, as well as visually to minimize interpolation artifacts that can arise.

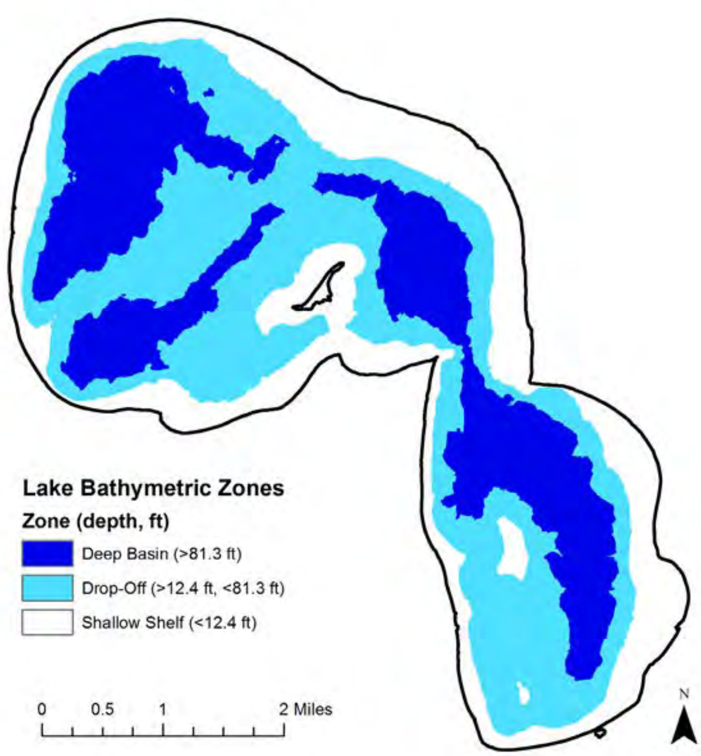


Figure 2.2.7. Map of the lake bathymetric zones used for the zonal kriging method.

The final output from the zonal kriging method is shown as a relief map in Figure 2.2.8. This new map provides an unprecedented level of detail, both in the shallow region of particular interest to this study, as well as in the steep drop-off of critical ecological importance, and in the deeper basins as well. This data could also be used to provide better navigational data for the lake, particularly for highlighting hazards that arise due to lake level fluctuations. Furthermore, it can be used as a baseline dataset to assess future changes in lake bathymetry that might result from continued shoreline erosion, or lake level changes.

For the sake of comparison, contours were generated from the new map (FIgure 2.2.9) that match those in the original 1939 dataset (Figure 2.2.10). While making direct inferences between these two maps should be done carefully because of the errors in the original map dimensions, there are some notable differences in positions of the 10 foot contour (Figure 2.2.11). In particular, the new 10 foot contour is almost always located toward the deep basin relative to that in the 1939 map. If differences between the two maps were random this would not be the case. Furthermore, there are several areas of distinct differences, which in comparison to the erosion likelihood map (Figure 1.8.5) show commonalities. Together, these are suggestive, though not definitive evidence for, shoreline-erosion induced changes in the location of the 10 foot contour resultant from the movement of sediment eroded from the shoreline.

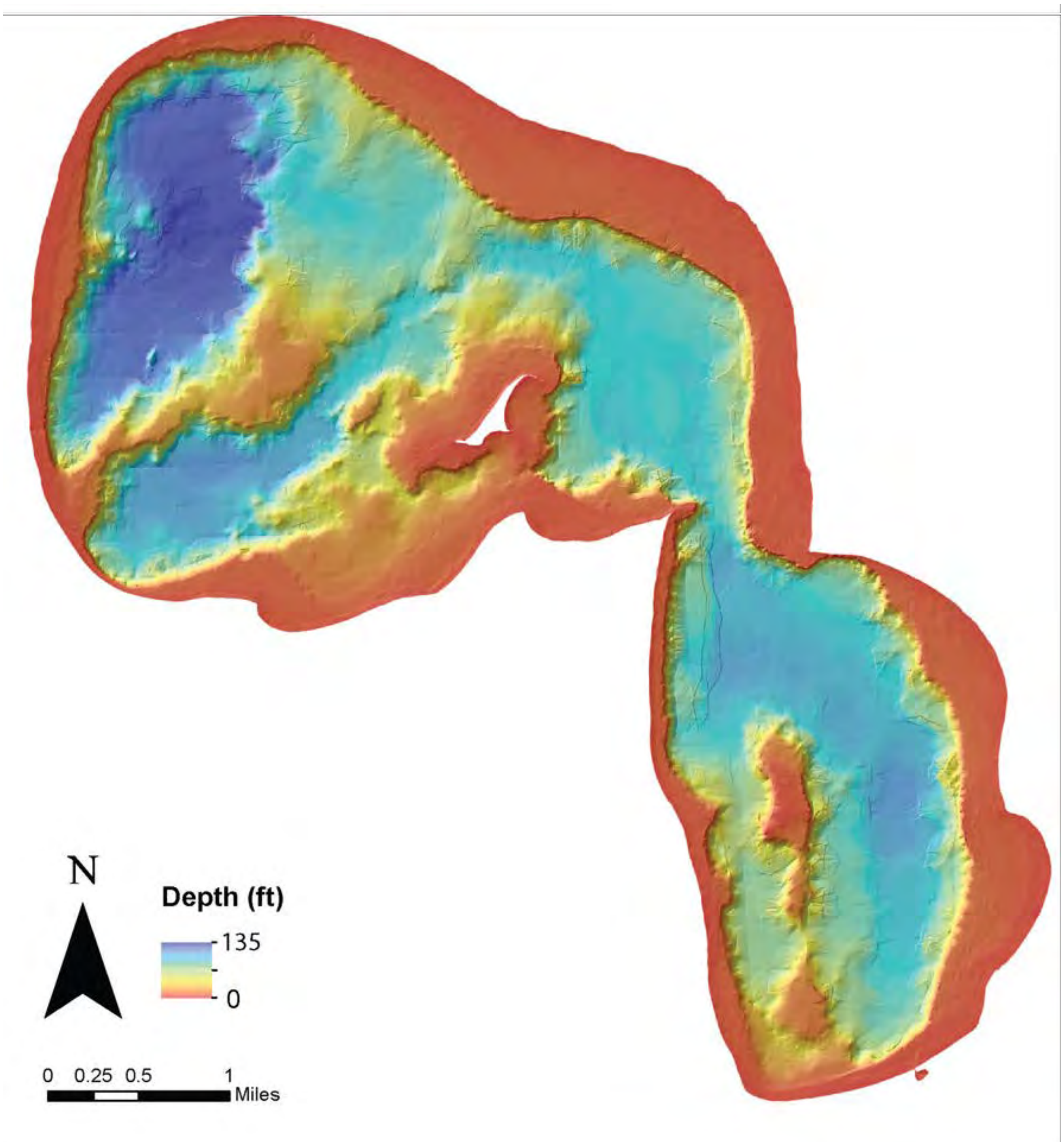


Figure 2.2.8. Relief Map created using the bathymetric data collected by UM and MSU during 2013 and 2014. The image is constructed using a 3x3 meter cell size.

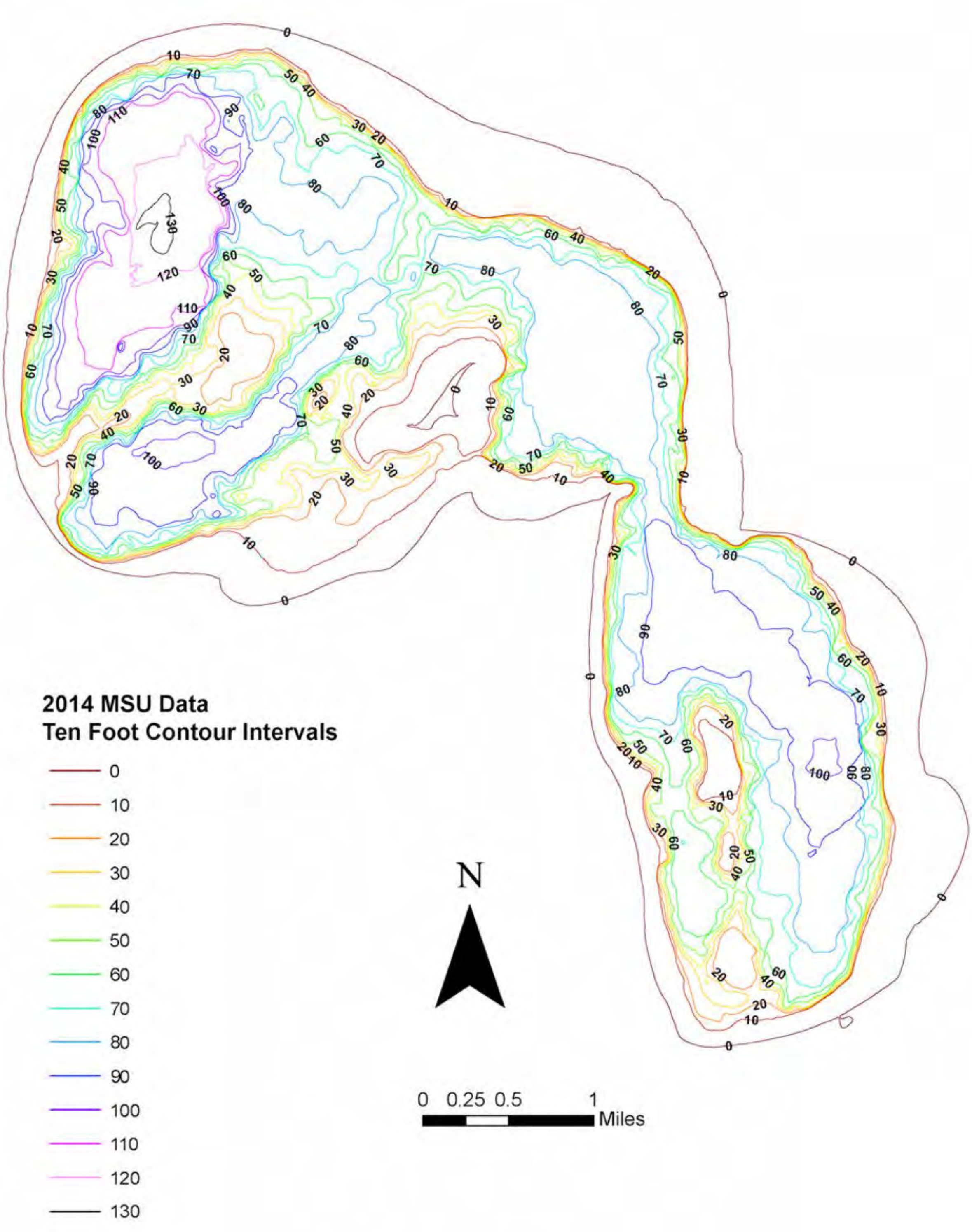


Figure 2.2.9. New bathymetric map contoured at 10 foot intervals.

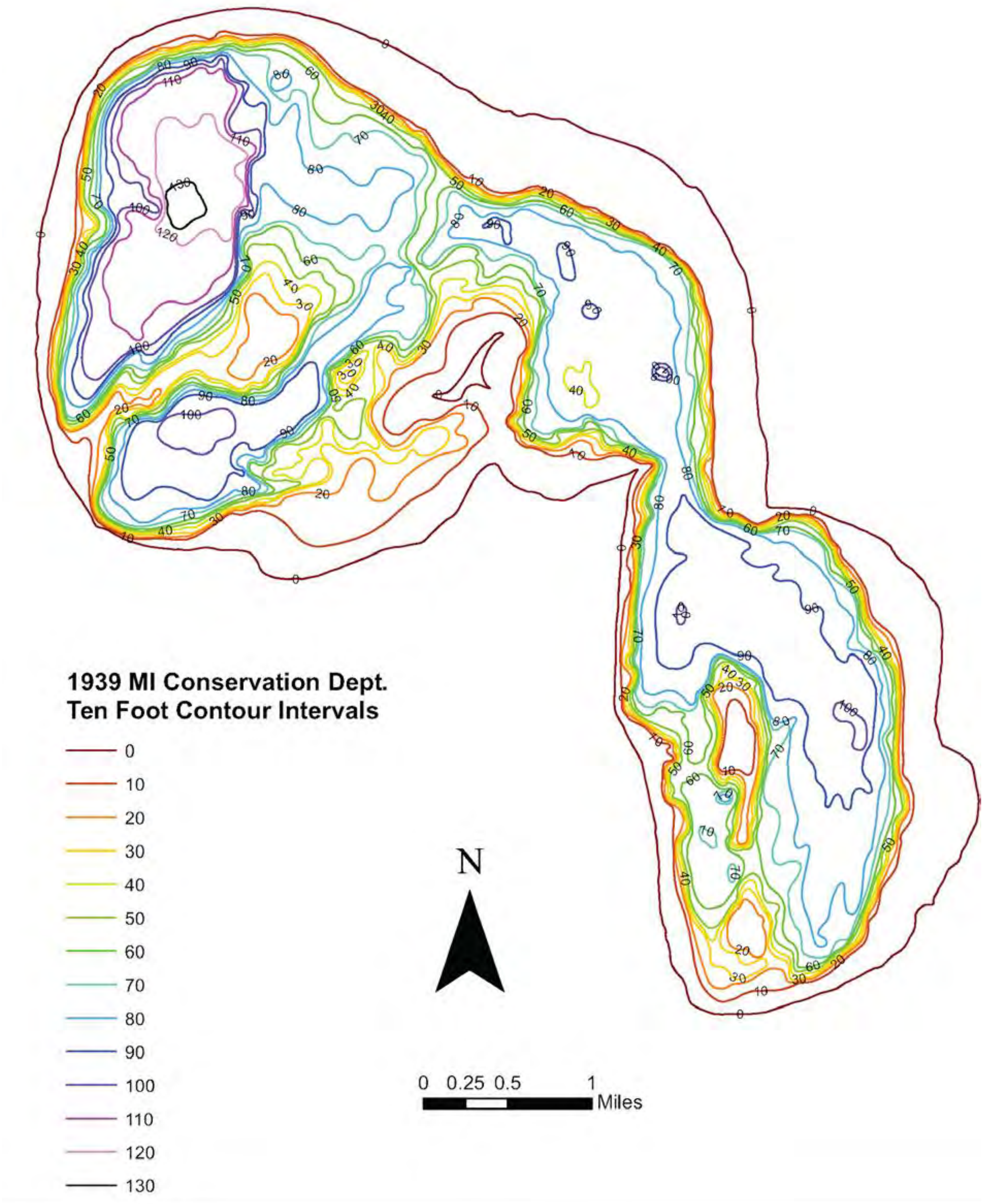


Figure 2.2.10. The original 1939 Michigan Conservation Department bathymetric map digitized and displayed in the same color scheme as the new contour map.

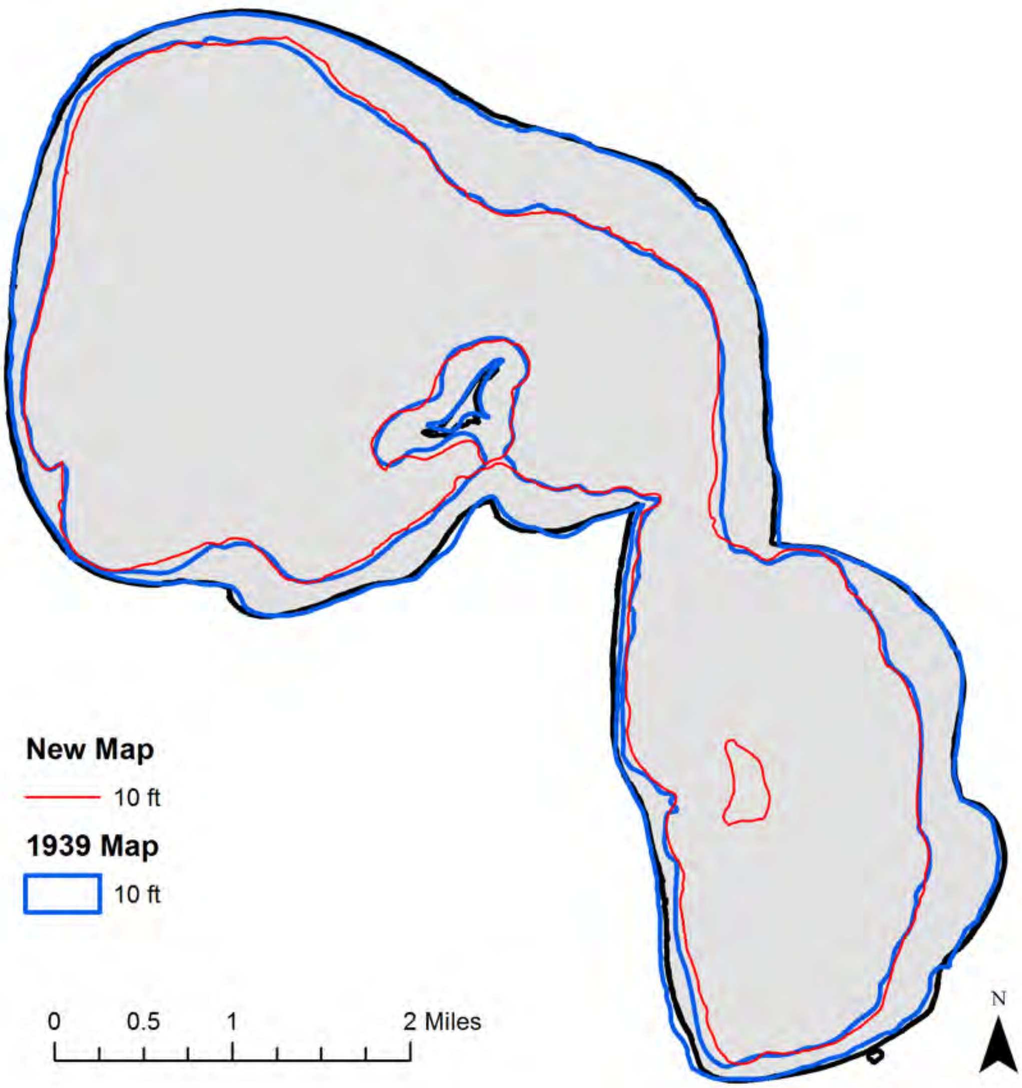


Figure 2.2.11. Map comparing the new 10 foot contour (red) to that of the original 1939 map (blue). Note that the outer blue ring should overlap the black lake outline, where it does not there are errors in the original map dimensions and care should be taken in interpreting differences between the new and old 10 foot contours.

2.3: Evaluation of Lake Level Scenarios

Now that a comprehensive digital map of Higgins Lake bathymetry is available, the impacts of changed lake levels can be assessed on a variety of important areas: 1) changes in shoreline position (and lake area), 2) dredging that would be necessitated at lake access locations and marinas, and 3) changes in dock length by residents of the lake.

Changes to Shoreline Position and Lake Area

Perhaps no impact of changed lake level is as significant as changes in shoreline position. This impact would be felt most directly in terms of increasing the length of beach between the lake and property owners, providing a buffer from erosion and in some cases substantially increasing property sizes. Lake area would decrease in direct proportion to the increase of riparian landowner property area, with all of the changes occurring in the shallow shelf region.

Contours were created at depths of 4, 6, 9, 13, 18, and 20 inches relative to the current summer legal lake level (Figure 2.3.1). These contours show some areas where shoreline changes would be significant across the more extreme scenarios, particularly in the North Basin and in the South Basin adjacent to South Higgins Lake State Park. We assumed that a new shoreline would form at approximately the location of the depth contour representing that lake level drop (i.e. a 6-inch drop shoreline forms at the 6-inch depth contour).

To more quantitatively assess how shoreline positions change, shoreline changes were averaged within polygons encompassing 250 meters (820 feet) of Higgins Lake shoreline--the same analysis sections used in the erosion likelihood map (Figure 1.8.7), and armoring percentage map (Figure 2.1.1). While each scenario was assessed, only the 4-inch and 9-inch drop are displayed. These were chosen because they represent the mean conditions of two altered dam-management strategies (keeping the dam open at all times, and removing it) discussed in greater detail in Task 5.4.

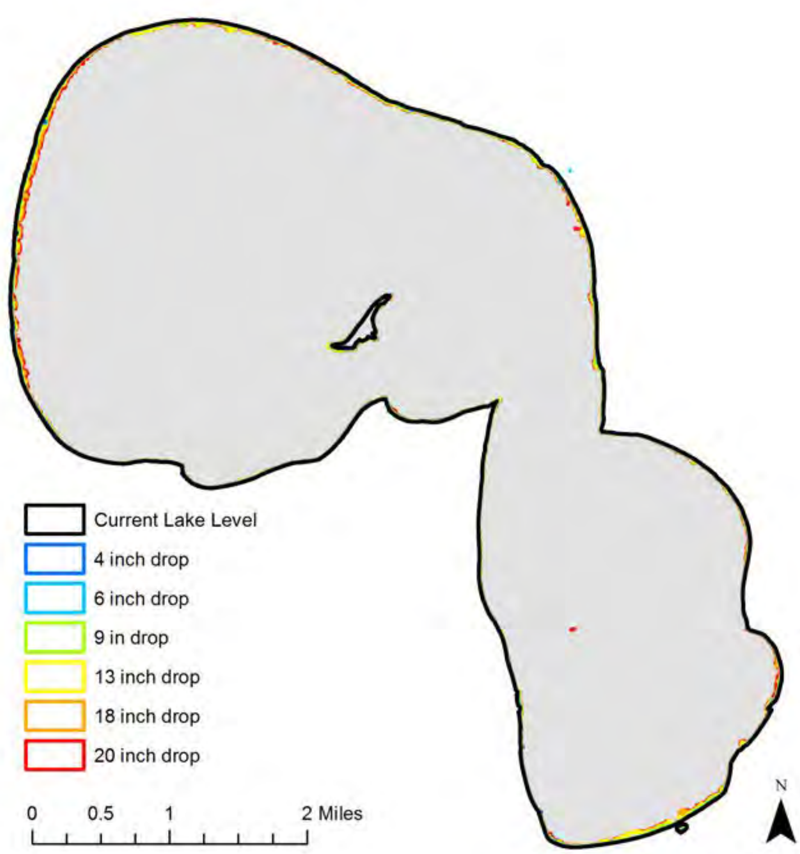


Figure 2.3.1. Map of shorelines overlain from each lake level drop scenarios.

In Figure 2.3.2 below, the 4-inch lake level drop scenario is shown. The area of most significant change is on the western edge of the North basin, while the area with least change is on the western edge of the South basin. Changes ranged from 9.3 feet to as much as 24.6 feet, on average across the 820 foot wide polygons. These numbers represent a recession of the shoreline away from the current lakeshore toward the center of the lake, thus increasing the buffer between properties and increasing total dry property dimensions.

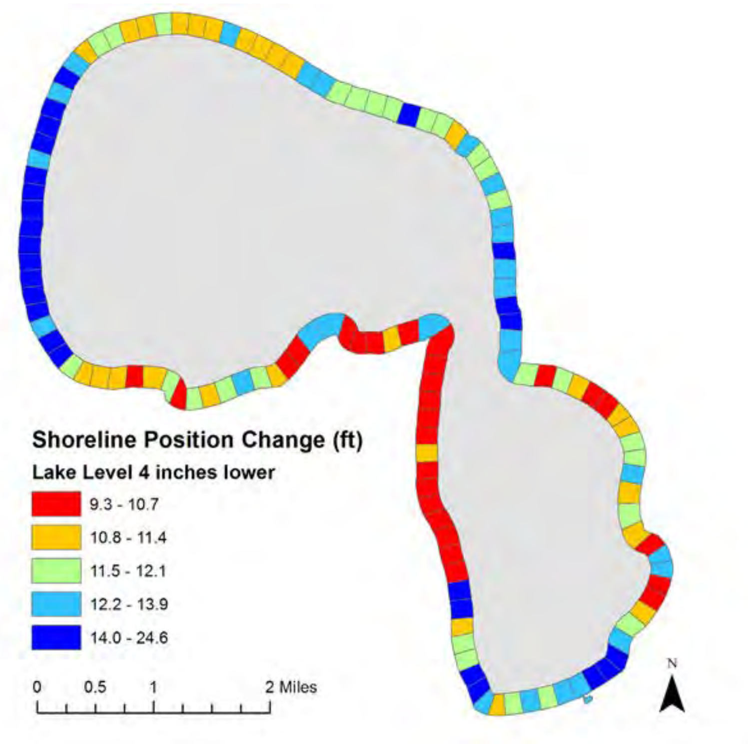


Figure 2.3.2. Map of shoreline position changes (toward the center of the lake) under a 4-inch lake level drop scenario. Colors indicate 20% quantiles of

shoreline position changes across analysis polygons.

A similar map for the 9-inch lake level drop is shown in Figure 2.3.3, with similar patterns of change but larger overall magnitudes. Here changes range between 15.7 and 62.9 feet.

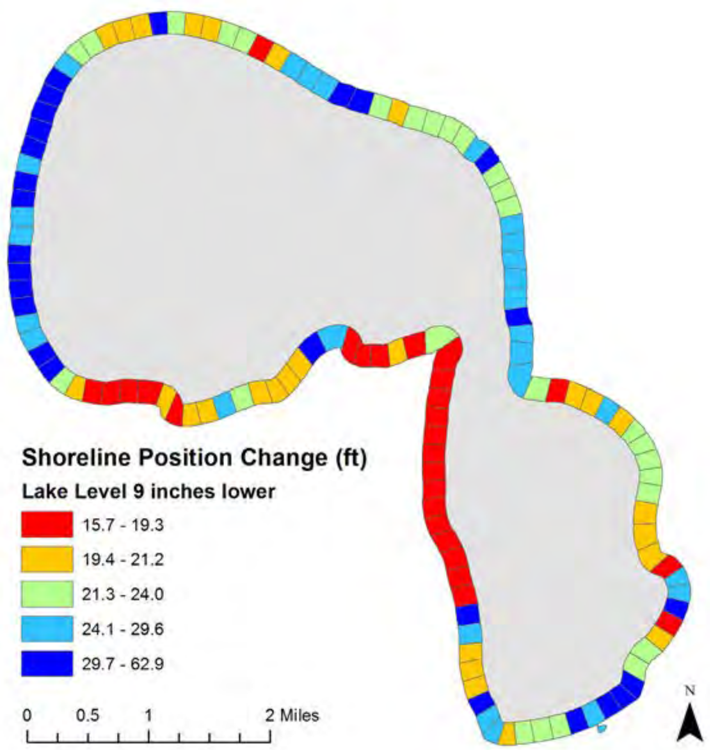


Figure 2.3.3. Map of shoreline position changes (toward the center of the lake) under a 9-inch lake level drop scenario. Colors indicate 20% quantiles of shoreline position changes across analysis polygons.

Averaging across all lake polygons for each scenario produces Table 2.3.1. From this table we see that on average shoreline position migrates lakeward by 12.3 feet in the 4-inch drop scenario, and as much as 83.6 feet in the 20 inch drop scenario. It should be noted here, however, that the lake level modeling in Task 5.4 shows that the more extreme scenarios are highly unlikely to occur, *even in the absence of any lake level control structure*.

Shown in Table 2.3.2 is the change in lake area as a result of each scenario. For the 4- and 9-inch drop scenarios, lake area decreases by 25 and 69 acres, respectively (0.3 to 0.7% decline). The extreme scenarios show declines of as much as 2% or more of lake area, again with the caveat of high unlikelihood that these scenarios would ever occur. Note that all of the land lost by the lake is gained by riparian property owners.

Table 2.3.1. Shoreline position changes (toward the center of the lake) averaged across the analysis polygons for each of the lake level drop scenarios investigated.

Lake Level Drop Scenario (in)	Average Change in Shoreline Position (ft)

4	12.3
6	17.0
9	25.3
13	45.1
18	64.1
20	83.6

Table 2.3.2. Lake area for all scenarios, along with percent change in lake area calculated relative to current area.

Lake Level Drop Scenario (in)	Lake Area (acres)	Change in Area (%)
Current	10,258	
4	10,223	-0.3
6	10,210	-0.5
9	10,189	-0.7
13	10,140	-1.1
18	10,088	-1.66
20	10,043	-2.1

Changes to Depth in Dredged Areas

Several locations around Higgins Lake are currently dredged for boat passage and mooring, five of which are shown in Figure 2.3.4. These locations would be directly affected by any lake level change, and the need for dredging would increase.

Figure 2.3.4. Locations of the dredging volumes calculated. Areas were selected based upon the feasibility and reliability to delineate either boat launches or marinas via aerial imagery.

Using the scenarios for change in lake levels, researchers calculated the volume needed to be dredged to maintain a 3.3 ft depth within the boat launches and marinas. This depth was used out of simplicity since the original measurements were in meters and due to regulations for boat launches requiring a depths between 3 and 4 ft.

Because of the higher resolution needed for this assessment, a different methodology was needed to assess dredging requirements. First, by using the collected depth data from the Sontek ADCP of the nearshore and overlaying a grid, the areas of sparse data was manually interpolated. From these data points of each area of interest Thiessen polygons were constructed within ArcGIS. These polygons divide the area of interest into regions within which each known point is the nearest neighbor for interpolation. The Thiessen polygons were then used to calculate the surface area of each data point grid cell. Each grid cell was evaluated to determine the depth required to remain in compliance with navigational water regulations of 3.3 ft water depth.

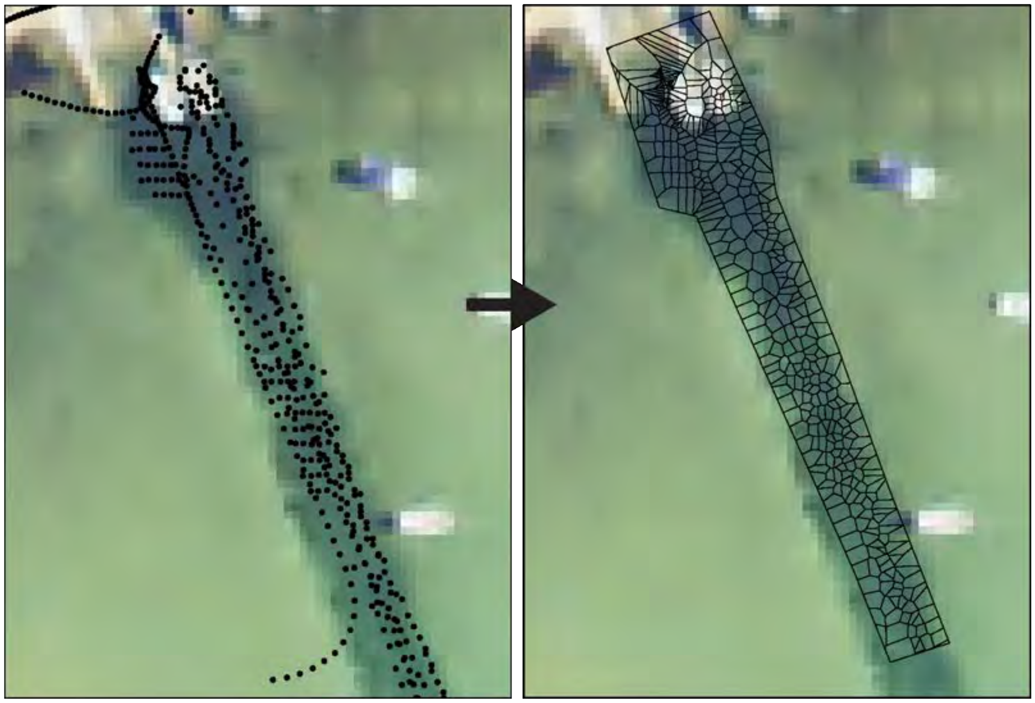


Figure 2.3.5. Graphic illustrating the workflow of calculating the dredging volumes of North Higgins State Park's boat launch. Black dots indicate the data points used to construct Thiessen polygons to calculate area

Note, not all marinas and launches met this current requirement, thus we quantified the dredging need under lake level change scenarios and subtracted out the current need (a dredging backlog, effectively). This isolates the changes caused by the lake level scenarios alone.

Table 2.3.3 lists the volumes for each area of interest and for each scenario. Clearly, South Higgins Lake State Park and B&B Marina would incur the greatest impacts in terms of dredging due to lake level changes. The other three areas of interest have approximately an order of magnitude less requirements. Note again here that the more extreme scenarios should be considered highly unlikely to occur, as mentioned above as well and below in Task 5.4.

Table 2.3.3. Dredging volumes for all lake level scenarios

Lake Level Drop Scenario (in)	Dredged Volume (cubic yards)	Marina/Boat Launch
4	914	B&B Marina
6	989	
9	1480	
13	2133	
18	3282	
20	3283	
4	45	North Higgins State Park
6	54	
9	72	
13	113	
18	195	
20	243	
4	89	Treasure Island
6	109	
9	141	
13	182	
18	234	
20	255	
4	53	West Higgins Boat Launch
6	75	
9	138	
13	251	
18	446	
20	533	
4	854	South Higgins State Park
6	1312	
9	2058	
13	3133	
18	4563	

20	5147	

Changes in Dock Length

Another direct impact of lake level changes would be in altering the lengths of docks required for adequate depths at the dock ends. This subtask quantifies those potential changes.

Dock presence was calculated in two ways: 1) Every dock was visually identified and photographed with a GPS-enabled camera during the 2012 bathymetric survey, and 2) All docks visible in satellite imagery from 2011 were drawn on a map. The two surveys produced different numbers of docks: 1207 (including approximately 30 potential duplicates) were photographed during the July in-lake survey, while 934 docks were identified from the June 21, 2011 satellite imagery. Potential sources for this discrepancy (about a 20% undercount from the satellite imagery) include variable times of dock installation by lake residents, as well as possible missed dock features (however the satellite imagery were very high resolution and docks were clearly identifiable).

Nevertheless, the satellite data were needed for quantitative analysis of dock length changes under different lake level scenarios. Figure 2.3.6 shows a zoom of the central portion of Higgins Lake with the manually digitized docks in that region. To quantify dock length changes independently of the exact dock count, as well as to increase the accuracy of the overall analysis, dock length changes under varying lake levels were analyzed within 250 meter (820 foot) shoreline polygons, rather than on individual docks.

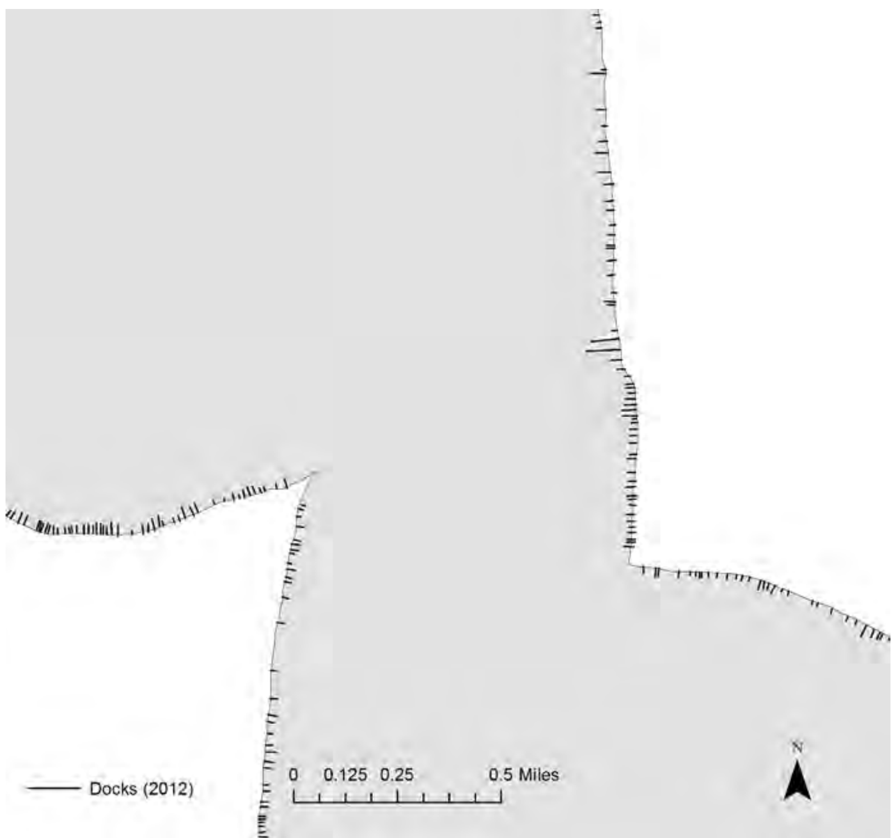


Figure 2.3.6. Map showing docks manually digitized from satellite imagery from 2011. Each black line is a single dock in this map. This map is zoomed to the central portion of the lake to enhance detail of individual docks.

Before deciding on a method to quantify dock length changes, the researchers consulted the literature on how nearshore depth profiles change as a result of water level changes. The outcome of this literature review was that the issue is extremely complex, and beyond the scope of this study. Nevertheless, we developed a conceptual model for how dock lengths would change as the nearshore profile evolves in response to lake level changes. This model is drawn in Figure 2.3.7.

Step 1 of this graphic shows the current situation, where the lake depth quickly increases very near the shore and then slows to a more gradual increase with greater distances. A dock located at this point has a depth presumably set to allow navigation for a particular watercraft or recreational use.

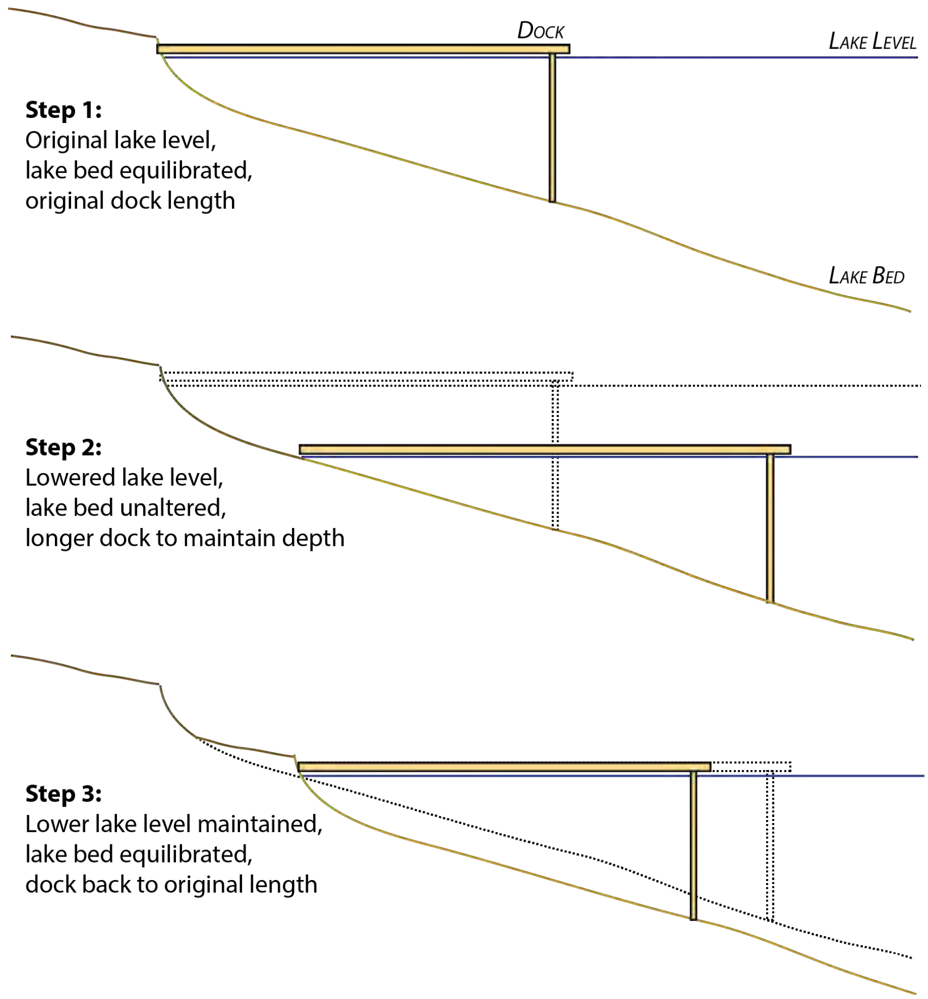
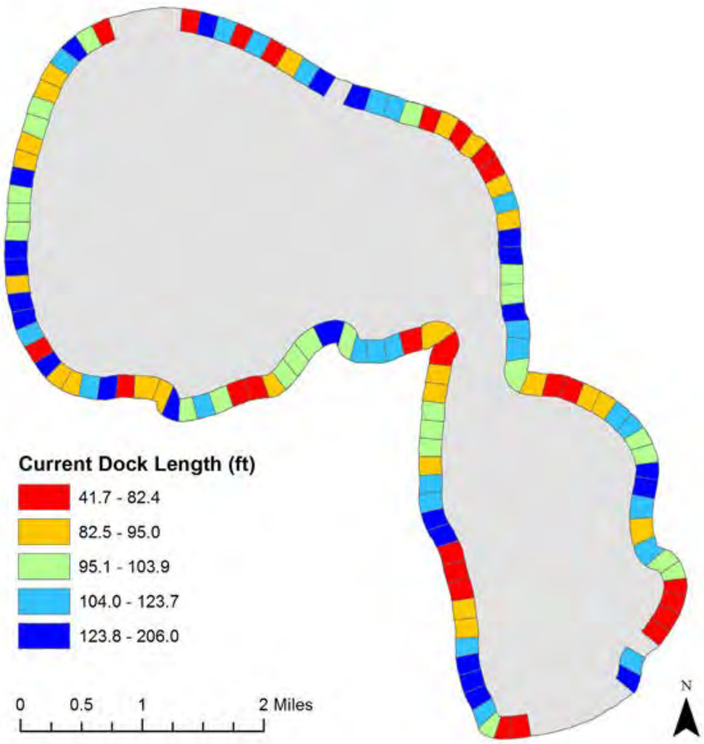


Figure 2.3.7. Conceptual diagram of how the lake bed profile might evolve in response to lowered lake level.

Step 2 shows the immediate aftermath of a significant lake level decline. The lake bed has not had time to adjust, the dock is moved outward to the new shoreline location, and lengthened in order to maintain adequate depth at the end of the dock.

Over time, however, as the lake redistributes sediment in response to the lowered depth, the profile will likely evolve to something approximating the original profile. This profile is controlled by two factors: sediment supply, and wave energy. Assuming no change in armoring status, neither factor will be greatly affected.

Step 3 then displays the outcome of the evolution back to the original profile, where the dock can return to its original length, only now it is located lakeward of its original position.



With this conceptual model then, eventual dock lengths would likely be similar to their current lengths. These lengths are summarized in the now-familiar 250 meter (820 foot) analysis polygons. Dock lengths average between 42 and 206 feet across these polygons.

Figure 2.3.8. Map of current dock lengths averaged within polygons each covering 250 meters (820 feet) of shoreline. Only polygons with docks at the time of the analysis are shown. Colors indicate 20% quantiles of dock length.

The actual procedure to calculate the changes in dock length within each polygon proved to be somewhat complex. Each polygon was allowed to have its own average dock-end depth, which necessitated creating a whole series of contours of depth across the lake, intersecting them with polygons, and then looping over the scenarios.

The outcome of this analysis should be considered a *temporary* change in dock length that would be produced only if the lake level were dropped over a very short time period. A more careful management strategy would assess changes in depths that occur in response to both lake level lowering and subsequent sediment redistribution, particularly following ice-free storm events.

Figure 2.3.9 shows the changes in dock length calculated with this method for the 4-inch drop scenario. Changes in length ranged from essentially 0, to as much as 257 feet in at least one polygon. These changes are not randomly occurring around the lake, and fall particularly heavily in the western section of the North basin.

Shown in Figure 2.3.10 are the changes for the 9-inch drop scenario. These are similar in pattern to Figure 2.3.9, only more extreme.

The across-polygon averages are detailed in Table 2.3.4. On average, dock lengths would increase under this method by 73 feet for the 4-inch drop scenario, and 155 feet for the 9-inch drop. More extreme scenarios have greater average changes, with the same caveats as above. A second caveat with this analysis is added that this method is fairly simplistic, and does not account for the dynamic lake processes that shape the bathymetry of the shallow shelf zone.

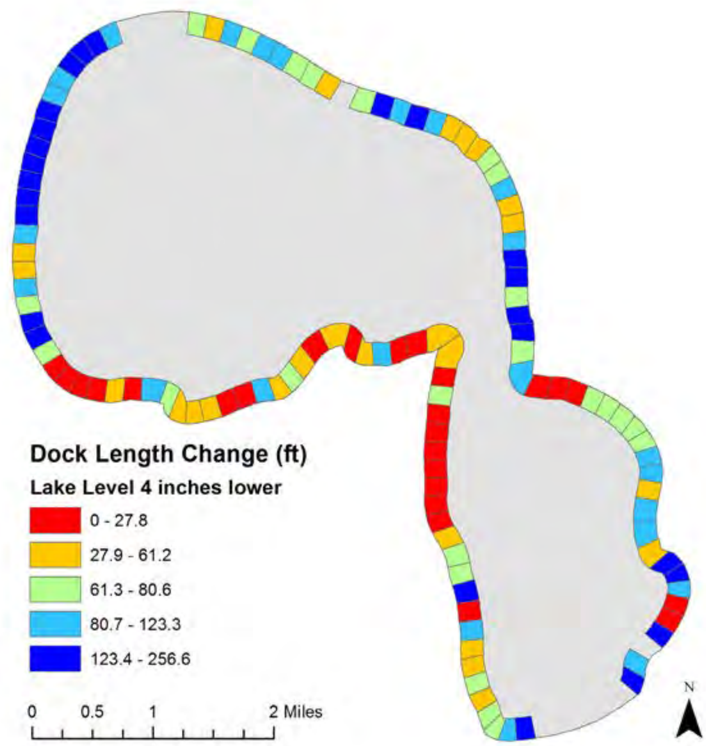


Figure 2.3.9. Map of dock length change (scenario - current) under a 4-inch lake level drop scenario. Colors indicate 20% quantiles of dock length.

Figure 2.3.10. Map of dock length change (scenario - current) under a 9-inch lake level drop scenario. Colors indicate 20% quantiles of dock length.

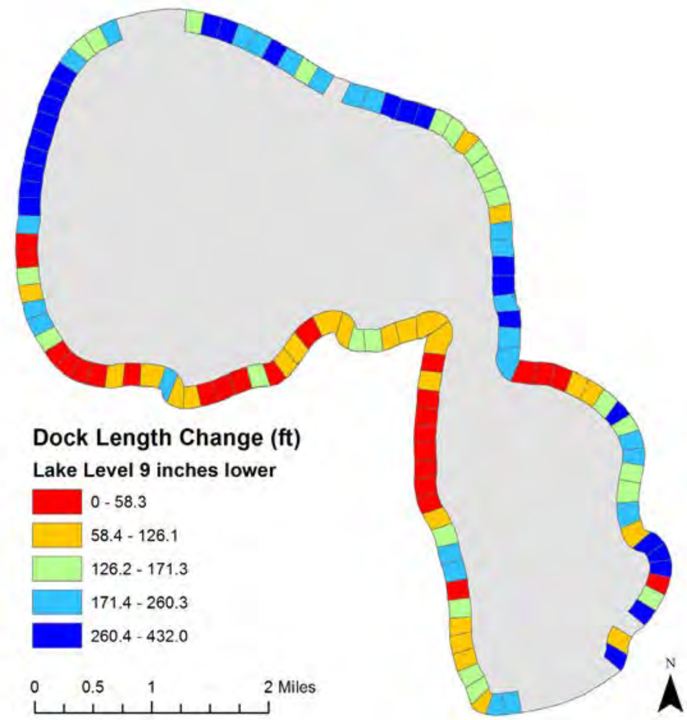


Table 2.3.4. Dock length changes averaged across the analysis polygons for each of the lake level drop scenarios investigated.

Lake Level Drop Scenario (in)	Average Change in Dock Length (ft)
4	73.0
6	108.1
9	154.7
13	186.7
18	244.5

Task 2 Findings Summarized

- A single lake level gauge proved sufficient for translating lake depths to bottom elevations in a multi-day, multi-team survey.
- New methods were pioneered to produce a highly accurate bathymetric map in the deep basins, steep drop-offs, and shallow shelves of Higgins Lake.
- The new map provides unprecedented detail of Higgins Lake bathymetry.
- Evidence of change in position in the 10-foot contour between 1939 and 2013 is suggestive of sediment transport due to shoreline erosion.

- Shorelines change significantly under the most likely 4- and 9-inch drop scenarios, receding lakeward by 12.3 and 25.3 feet on average under these two scenarios respectively.
- Erosion impacts would be significantly lower under the lowered scenarios due to the increased land buffer and greater distance from structure and trees.
- South Higgins Lake State Park and B&B Marina would require dredging approximately 900 cubic yards of sediment under the 4-inch drop scenario, and 2000 and 1500 cubic yards in the 9-inch drop scenario. Other areas of interest saw lower declines.
- With ample caveats, dock lengths would need to increase significantly in the short term if lake levels were abruptly lowered, but over the long term would likely remain similar to those in use now.

Task 3: Cut River Morphological and Flow Surveys

This Task entails a detailed characterization of the morphology (channel shape and position) of the Cut River and how streamflow changes along its length in response to groundwater inputs.

3.1: Stream Profile Data Collection

In May of 2013, the MSU and UofM teams floated the entire length of the Cut River in order to characterize the depth of the channel, its habitat diversity, and flow changes along its length. The plan was to traverse the Cut River during a period of baseflow and before leaf out to ensure GPS coverage. During this process, the MSU crew towed the same Acoustic Current Doppler Profiler (ADCP) used for the lake shelf bathymetry survey behind a canoe while following a zig-zag path down the channel. The ADCP simultaneously records location (X,Y) with an onboard GPS, total depth (down to approximately 15 feet), flow velocity beneath the unit at multiple depths, movement relative to the stream bed, and a number of other parameters. Thus, it can be used to build a complete profile of stream channel depth. The instrument records each parameter once per second. The ADCP setup is shown in Figure 3.1.1.

Figure 3.1.1. Field setup for collection of stream profile data, with an ADCP towed behind a canoe.

The Cut River was floated during a two-day float, stopping at West Lansing Road at the end of Day 1 (May 23rd, 2013), returning for the remainder of the channel on Day 2. A map of all non-zero depth measurements from the ADCP is shown along the boat track in Figure 3.1.2. At the end of Day 1, due to battery issues, the onboard GPS cut out, and the position was inferred using the bottom track position alone--which can accumulate errors. This accounts for the mismatch between the boat track and the channel position beginning midway between the stream gauges HL-CR-4 and HL-CR-2 (described in Task 4). After the batteries were recharged overnight, GPS signal was maintained for the remainder of the float. In general, median track depths were approximately 2.1 - 2.2 feet, shallowest track depths of approximately 0.7 feet and deepest of 8.1 feet.

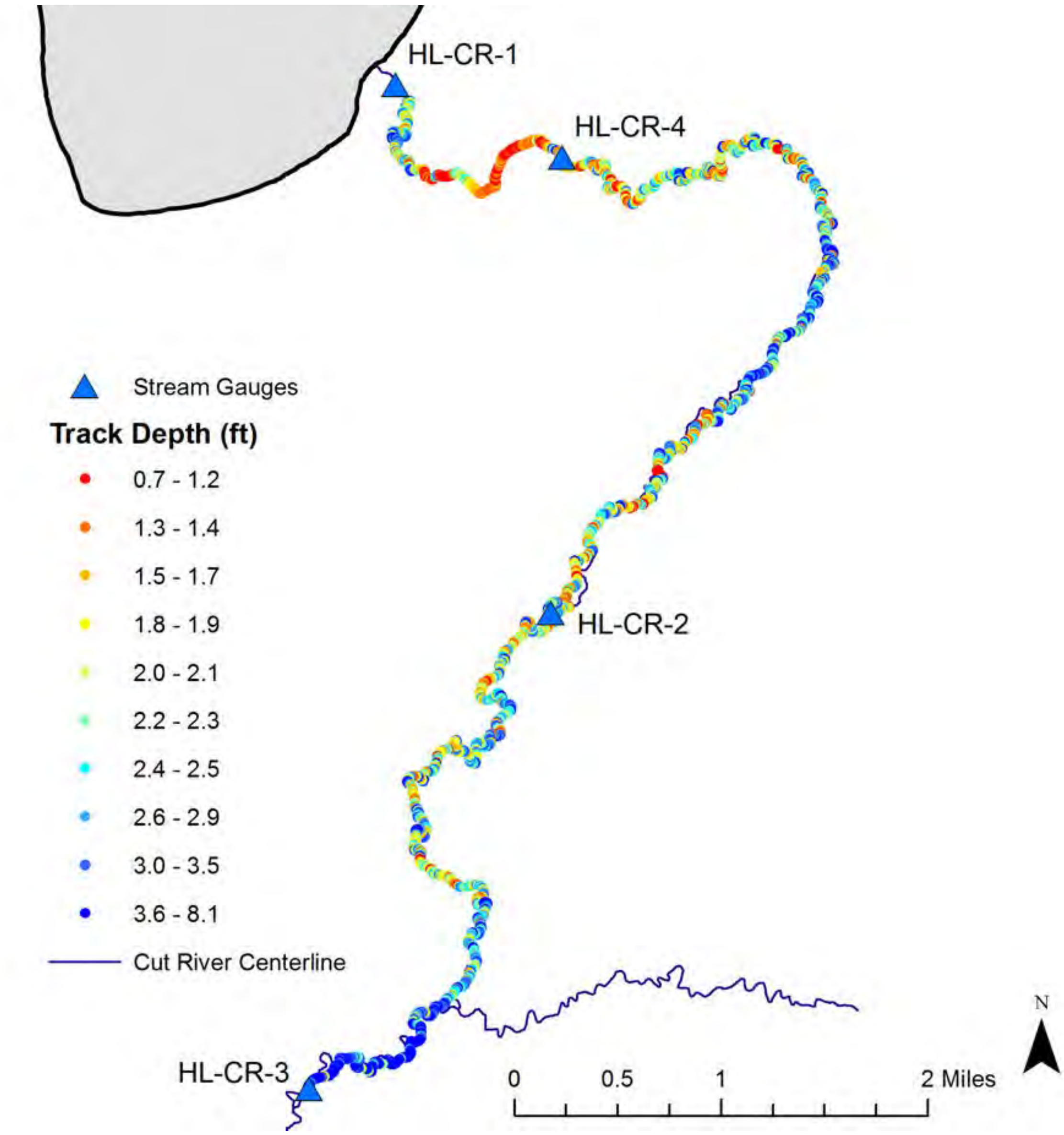


Figure 3.1.2. Map of continuous depth measurements made along the Cut River and through Marl Lake. Note some deviations from the main channel due to discontinuous GPS data above HL-CR-2. Colors represent 10% quantiles of channel depth.

To better understand how the data collected along the zig-zag boat track correspond to average channel depth (an important ecological habitat parameter), the measurements were matched to the channel position, and then averaged along each 50 meter (164 foot) length of channel. Average depths in the channel are shown in Figure 3.1.3. There are clearly bulk sections of the channel that are shallower (including Marl Lake), and in proximity to HL-CR-2, as well as deeper sections, mid-way between HL-CR-4 and HL-CR-2, and then again downstream of the confluence with Backus Creek. In general, median channel depths were approximately 2.3 - 2.4 feet, with shallowest average depths of approximately 0.9 feet and deepest of 7.2 feet.

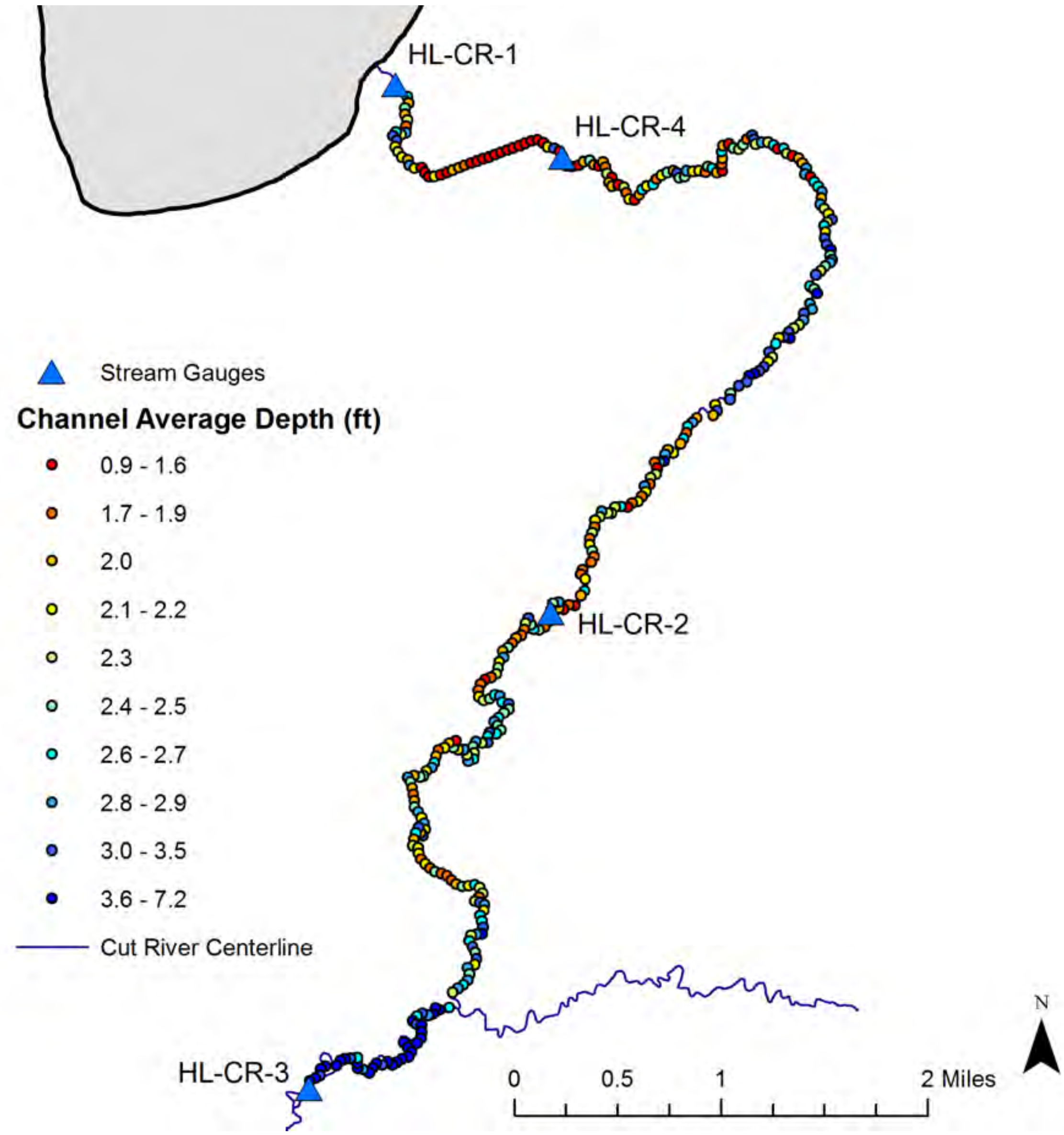
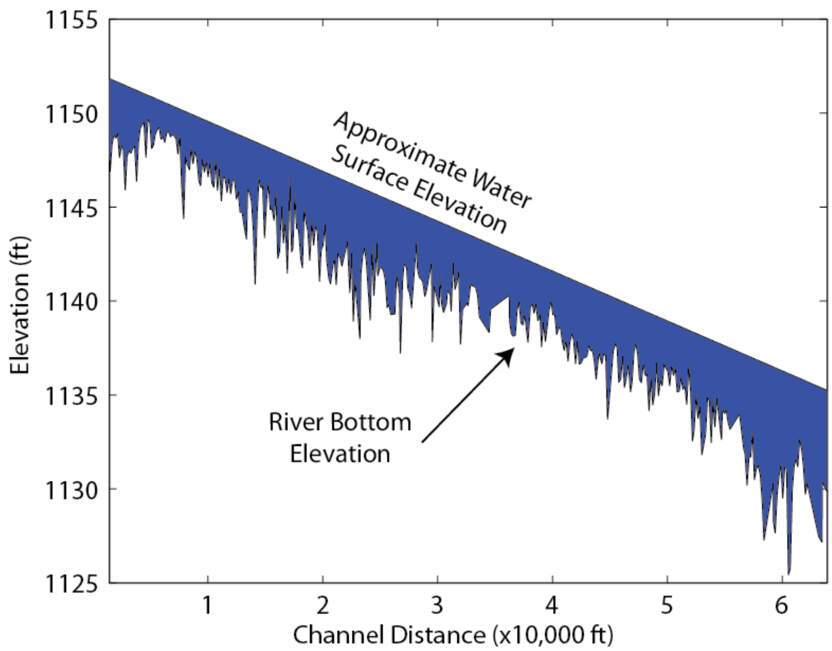


Figure 3.1.3. Map of depth measurements averaged along the stream channel. The actual boat track followed a zig-zag pattern down the channel, thus this represents rough averages along each 50 meter (164 feet) channel section. Colors represent 10% quantiles of channel depth.

Viewed another way, Figure 3.1.4 plots the deepest portion of each 50 meter segment, also known as the channel thalweg, as elevation down the channel. Due to discrepancies in channel elevation data among the multiple sources collected for this project, approximate linear water surface elevation is shown instead, roughly matching the elevations of Higgins and Houghton lake at the upstream and downstream ends, respectively. Clearly, after the confluence with Backus Creek, flow is hydraulically restricted by the channel depth and proximity to Houghton Lake. This is a historical consequence of the elevation of Houghton Lake and the subsequent flooding of the surrounding area. This region of the river is unique, with multiple winding distributary channels and deep, slow, river flows. Above that, however, the stream has a moderate gradient, with minimally impeded flows.

Figure 3.1.4. Plot of approximate river thalweg (deepest point in the channel cross-section) versus channel distance, starting at the gauge HL-CR-1 and ending at HL-CR-3.



3.2: Cut River Longitudinal Flow Profile

During the float, the crew paused intermittently to collect cross-sectional flow and velocity measurements of the channel. One such measurement is shown, taken just upstream of the HL-CR-2 (West Lansing Road) gauge site (Figure 3.2.1). In this procedure, the ADCP is attached to ropes and pulled laterally across the stream by people at either bank. This is repeated multiple times and the resultant flow measurements averaged to better quantify the true flow, as well as estimate flow uncertainties. Channel flows are complex, and non-uniform. The ADCP provides an unprecedented view into how these flows vary across the channel and with depth.

In total, the crew stopped to measure 17 flows during the two day float. The float began immediately after three gates on the dam were opened, sending a flood wave downstream. The first four stops all had flows in excess of 100 cubic feet per second. Across Marl Lake however, flow was back down to roughly 49 cubic feet per second, showing the role of Marl Lake in buffering flood wave progression downstream. Because of this, the team decided to install a fourth gauge, HL-CR-4 (on May 28, 2013), at a point just downstream of the Marl Lake outlet to better understand its role hydrologically.

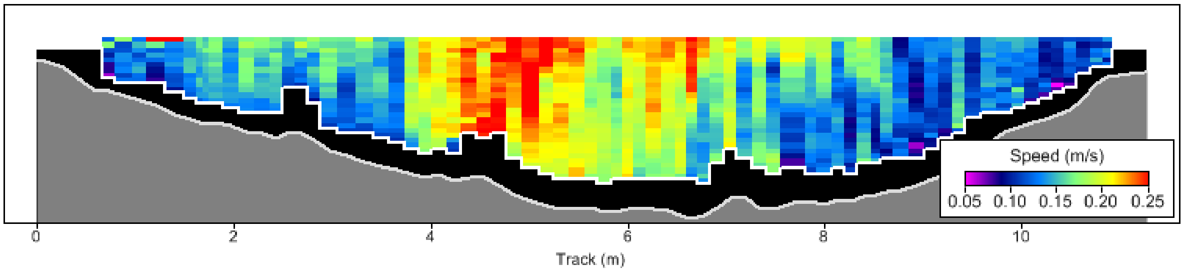


Figure 3.2.1. Example ADCP cross section showing channel depth and width with flow velocity as colors (from site HL-CR-2).

As Marl Lake acts a retention pool for the water it also has the potential to acts as a sediment trap. Local fisherman repeatedly complained about how Marl lake has become a “mud hole” and the depth has been becoming shallower. This fisherman also stated that the fish diversity has changed over the years. This could possibly be due to annual variability but, since UM or MSU did not perform a bathymetric survey of Marl Lake, it is unknown if or how changes have occurred.

From the Marl Lake outlet to West Lansing Road, the Cut River gained approximately 15 cubic feet per second in flow. A repeat measurement at the same point showed that flow had increased little due to the flood wave upstream by the start of the second day. Continuing downstream to a point shortly before the Backus Creek confluence, flow increased by only 8 cubic feet per second (cfs), but then added another 30 cfs after joining with Backus Creek. The system continued strongly gaining flow for the remainder of its short traverse to Houghton Lake, suggesting a strong groundwater input at this section.

Overall, by the time the Cut River reaches West Lansing Road, flow from the outlet of Higgins Lake accounted for approximately 77% of the flow in the channel. By the confluence with Backus Creek it was down to under 50%, and by the time the Cut River reached Houghton Lake the flow from the outlet of Higgins Lake accounted for under 33% of the total channel flow.

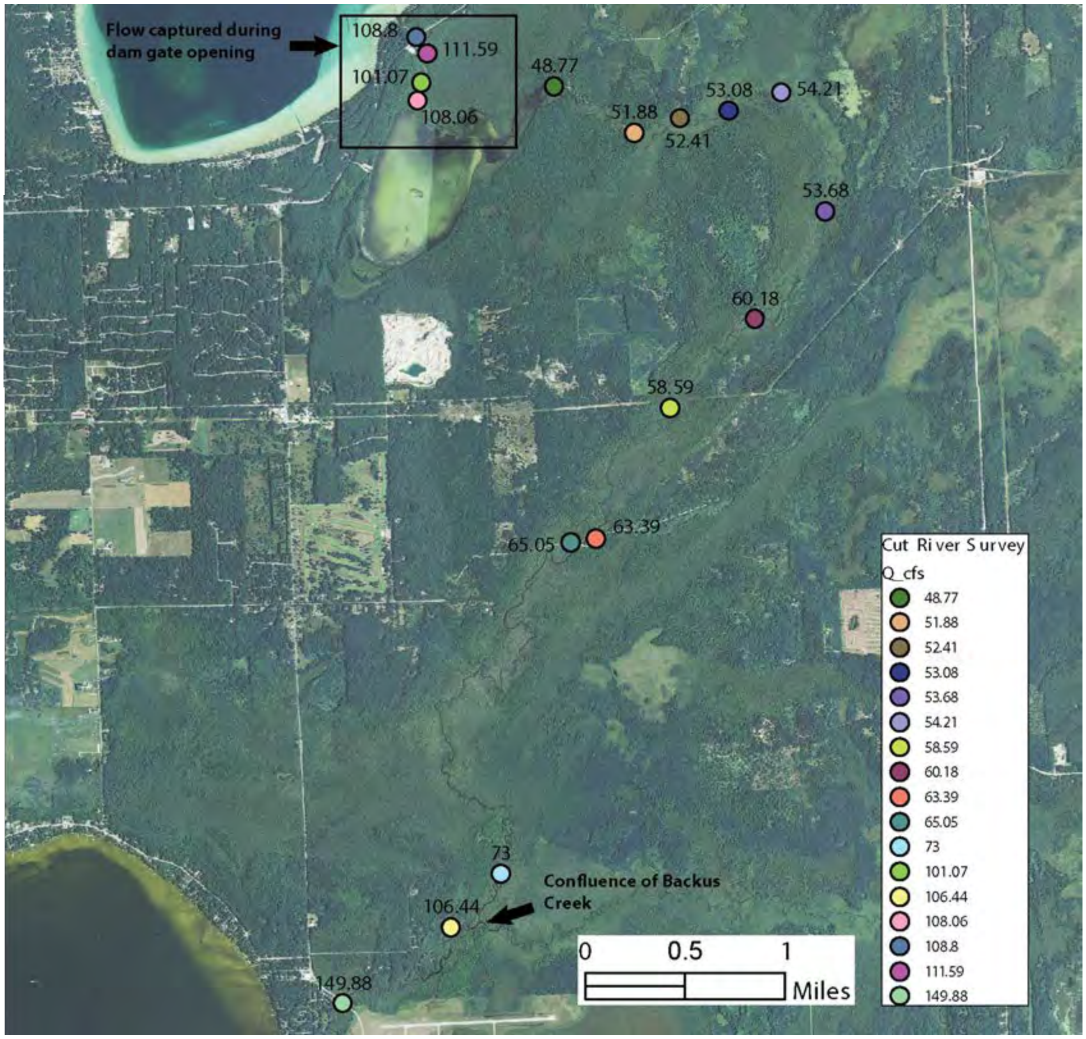


Figure 3.2.2. Map of all ADCP flow cross sections (late May 2013 flow cross sections)

Task 3 Findings Summarized

- The Cut River is in most places approximately 2.3 feet deep on average, and flows relatively swiftly during moderate flow periods.
- Downstream, near Houghton Lake, the Cut River is backed up due to the flooding of the land that formed the present day Houghton Lake. These are where depths in the channel are greatest.
- The Cut River is a beautiful and ecologically significant stream, flowing unimpeded through miles of wetland and stream habitat. Its diversity provides an excellent recreational resource as well.
- More than 75% of the flow for the Cut River upstream of West Lansing Road comes from Higgins Lake during baseflow periods.
- Additional flows from surface water and groundwater downstream of Backus Creek significantly reduce the impact of Higgins Lake outlet flows on Houghton Lake inputs.

Task 4: Install Flow Monitoring Equipment on Cut River

Continuously monitoring streamflow provides an excellent data source to more fully understand the hydrologic function of a system. This Task describes the installation and maintenance of four water depth recording gauges, and how those gauges can be used to quantify streamflow and learn about system behavior in response to dam management.

4.1: Gauge Installation and Maintenance

On July 28th, 2012, the MSU crew installed three automated data logging pressure transducers and temperature probes. These probes recorded data every 30 minutes. Figure 4.1.1 shows two photos of these gauges and their installation. The procedure consists of installing a gauge inside of a PVC housing attached to a fence post driven into the streambed. At that time, streamflow is measured across the channel, and the height of the water is recorded both by the instrument as well as on a manual water level gauge attached the the outside of the housing.

Figure 4.1.1. Installation of a stream gauge and discharge measurement on the Cut River at West Lansing Road (Site HL-CR-2).

Figure 4.1.2 shows the locations of the first three sites installed on July 28th: HL-CR-1 at East Higgins Lake Road, HL-CR-2 on West Lansing Road, and HL-CR-3 on East Houghton Lake Drive (M-100). These gauges were maintained until July 2015, when they were retrieved with their housings left intact for later redeployment if desired.

A fourth site, HL-CR-4 was added immediately downstream of Marl Lake after the role of Marl Lake in buffering flows was made evident in Task 3.

At the times of installation, a survey-grade GPS was used to measure gauge height and establish a local datum for each gauge-allowing for elevation corrected streamflows to be calculated.

Figure 4.1.2. Map of gauge locations, with dates of installation.

4.2: Rating Curves and Stream Flow

The gauges record water height above the gauge, which must be transformed to stream discharge via a rating curve. The rating curve defines a functional relationship between recorded stream height, and measured stream flows during specific site visits. In general, establishing a rating curve takes more than 4 measurements at various points along the curve, and further confidence is gained via repeat visits at a variety of stages.

During each visit, streamflow was measured using either the ADCP, or a cross-sectional wading method conducted with an OTT Acoustic Digital Current Meter (ADCM). Each are state-of-the-art measurement tools with interfaces that quantify the quality of stream discharge measurement and uncertainties in them.

Following the fourth site visit, rating curves were first established, that were then updated for each subsequent visit, provided that the flow measurement met the criteria for inclusion (an issue primarily impacting the HL-CR-3 site, which is hydraulically affected by Houghton Lake). The final curves after the latest visit are shown in Figures 4.2.1 and 4.2.2. R^2 values for these curves are all quite high, between 97.5% and 98.6%.

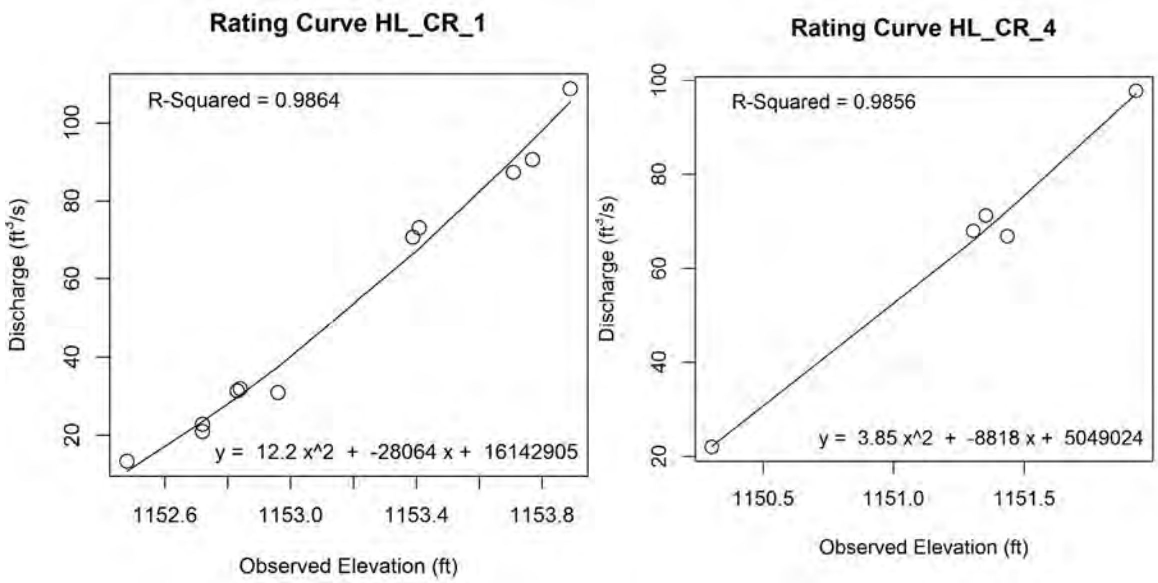


Figure 4.2.1. Rating curves for HL-CR-1 and HL-CR-4

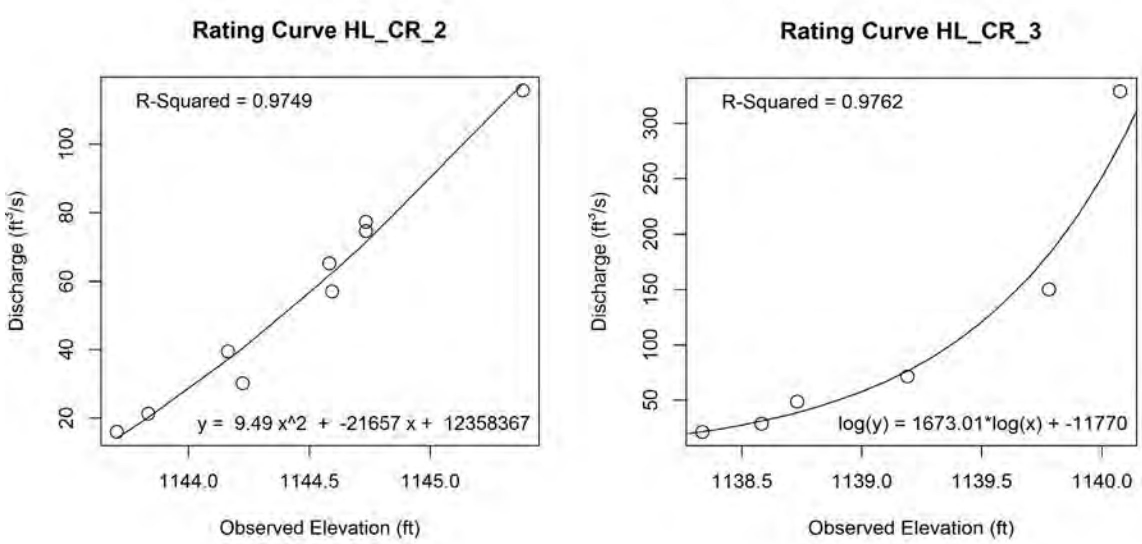


Figure 4.2.2. Ratings curves for HL-CR-2 and HL-CR-3.

Using these rating curves, and after transforming recorded stream stage to elevations using the surveyed site datum, continuous hydrographs for each site were developed (Figure 4.2.3). Significant gaps in the record occurred at sites HL-CR-2 and HL-CR-3 due to instrument and battery failures. All instruments were retrieved in July of 2015.

Site HL-CR-1 is clearly impacted by the management of the Higgins Lake outlet dam, where flows are abruptly discontinuous whenever gate configurations are significantly altered. For gate openings, the stream requires approximately 1 hour to fully equilibrate by the time it reaches HL-CR-1. Flows range between approximately 5 cubic feet per second to over 120 cubic feet per second at this gauge.

Flows at HL-CR-4 vary across roughly the same range as HL-CR-1, suggesting little to no gain in flows between them. Rather the highest flows are damped by Marl Lake. Responses to the dam configuration changes are muted in time due to Marl Lake, and examined further below.

The discontinuous record at HL-CR-2 (West Lansing Road) limits some of the conclusions that might be reached about relative flows, nevertheless peaks are significantly higher, approximately twice as high, than the upstream gauges. Though in lower flow periods the flows are roughly equal. HL-CR-3 shows significant gains in flow during wetter periods, commensurate with its larger surface and ground watersheds.

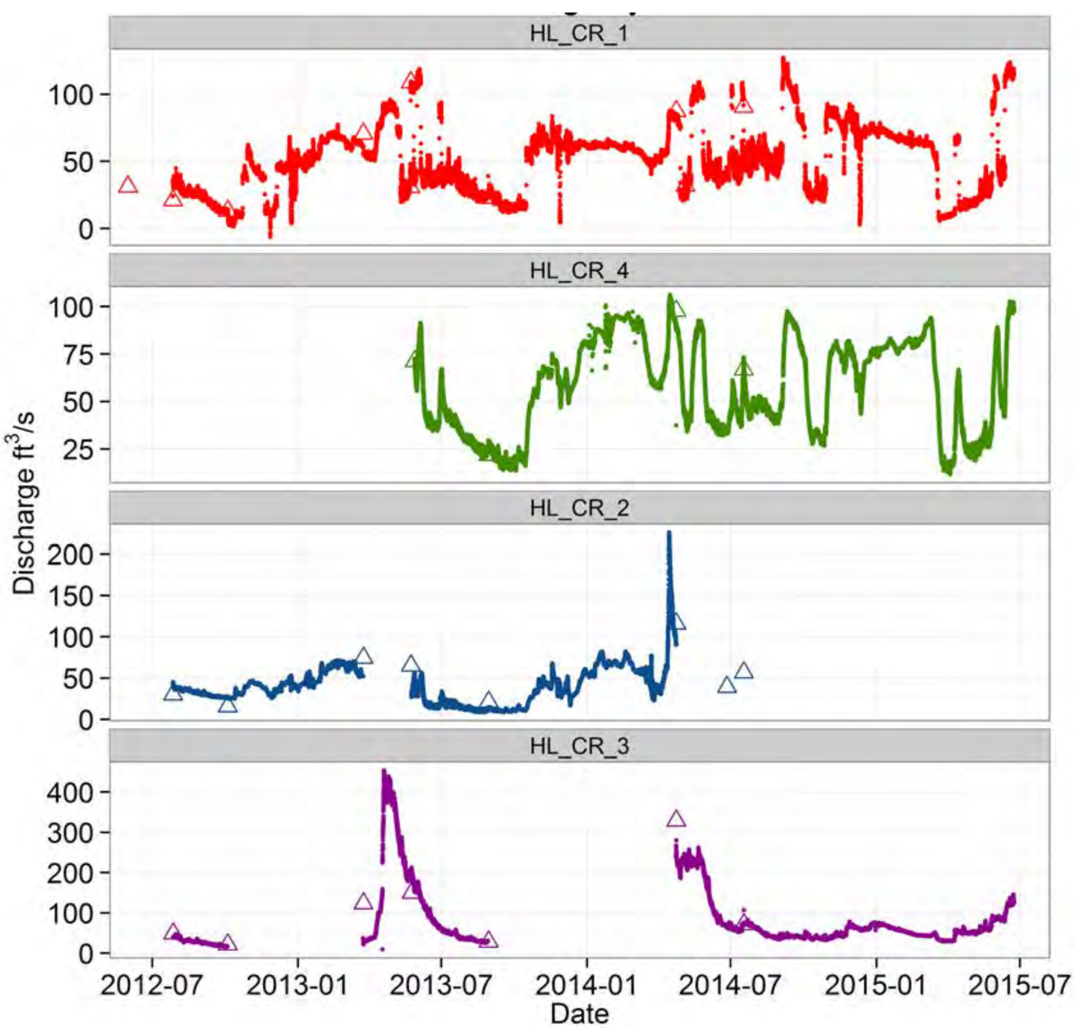


Figure 4.2.3. Rated discharge at all sites for the complete period of record. Observed flows are shown in similarly-colored open triangles.

To better compare relative streamflows, the four gauges are plotted for the most continuous segment in Figure 4.2.4. Here, the role of the downstream surface and groundwatersheds is obvious in determining total flow into Houghton Lake, particularly during high flow periods. During low-flow periods, Higgins Lake outflows account for a much larger proportion of streamflow entering Houghton Lake. Groundwater provides a significant boost in flows for gauges HL-CR-4 and HL-CR-2 downstream of Higgins Lake. Note that this occurs during the months and a year where net groundwater contributions from Higgins Lake are particularly negative (Figure 5.3.4), suggesting that the stream and Marl Lake may capture some of the groundwater lost from the lake during that period. 2013, a year with less groundwater loss from Higgins Lake, shows less of a flow increase.

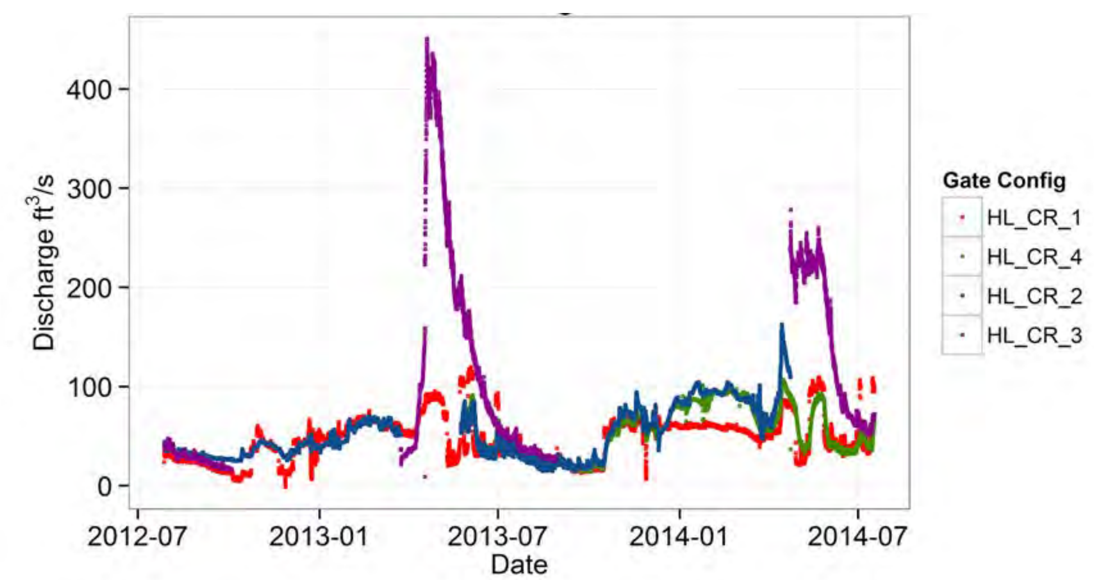


Figure 4.2.4 Rated discharge overlain for a two year period to show site flows relative to each other.

4.3: Dam Configuration Rating Curve

A significant unintended benefit of monitoring flow on the Cut River so close to the Higgins Lake outlet was the development of stage-discharge rating curves for various configurations of lake outlet dam gates. Using meticulous records kept by the Roscommon County Commission, and made available through the HLPOA website, data for the years 2012-2014 were digitized. The average daily flow was then classified based on the dam gate configuration, and outliers (which occurred on days where the gate configuration changed mid-day) were then removed. The result is Figure 4.3.1, which shows highly linear behavior of Cut River flows as a function of both Higgins Lake Elevation and outlet gate configuration.

In Figure 4.3.2, each gate configuration on Figure 4.3.1 was then regressed, producing four separate stage-discharge rating curves. These allow for much greater specificity in the role of the dam in managing lake levels, and should provide a benefit to the Roscommon county commissioners. With the exception of the dam fully closed rating curve, the R^2 for each of these regressions were quite good.

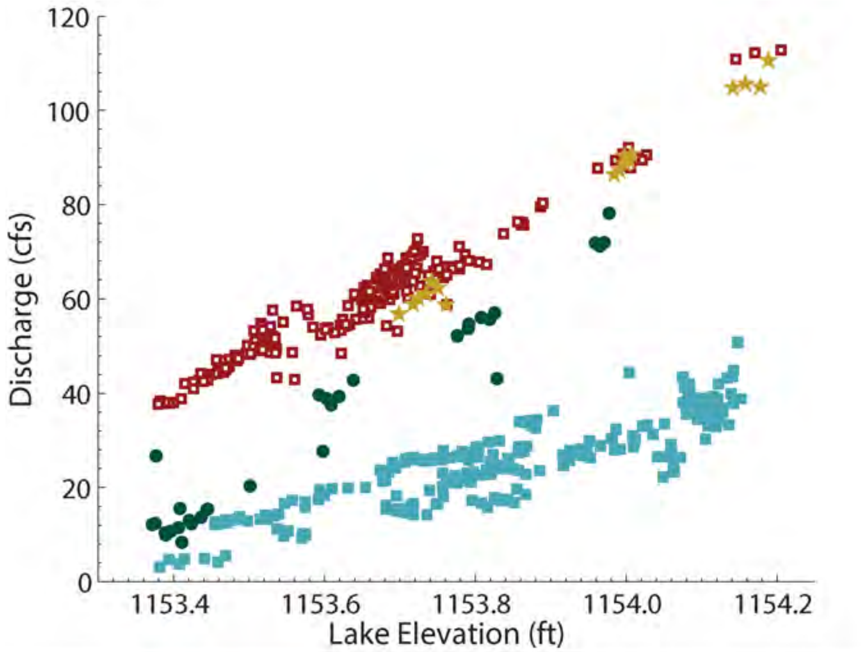


Figure 4.3.1. Discharge at the Higgins Lake Outlet (measured at HL-CR-1) as a function of lake elevation and dam Configuration. Data from 2012-2014. **Red Open Box**: All Flop Gates open; **Blue Box**: All Flop Gates Closed; **Slate**: One Flop Gate Open **Gold Star**: Two flop Gates Open; Flop gate 6 and the combination of Gates 4 and 5 were rarely used.

One interesting observation from Figure 4.3.1 is that for this three year period, the dam has largely been managed as "all closed" or "all open" with little use of either a single gate or two gates. Within this report, designation of "All Open" or "All Flop Gates Open" pertains to the tilt/flop gates 4, 5, and 6 of the lake level control structure. The scenario of "All Closed" or "All Flop Gates Closed" also only pertain to tilt/flop gates 4, 5, and 6. This is likely in response to the limited information available to the dam manager about how the dam should be operated to achieve specific level targets and over what time that target can be expected to be met and maintained.

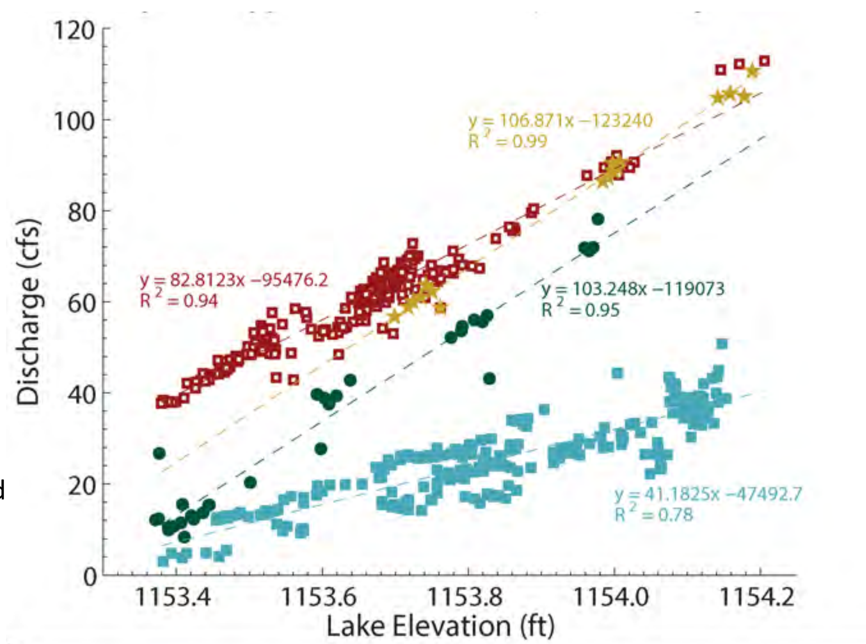


Figure 4.3.2. Rating curves of for each dam configuration. **Red Open Box**: All Flop Gates open; **Blue Box**: All Flop Gates Closed; **Slate**: One Flop Gate Open **Gold Star**: Two flop Gates Open; Flop gate 6 and the combination of Gates 4 and 5 were so rarely used we were unable to generate a realistic stage discharge relation.

4.4: Impacts of Outlet Control Structure Management on Cut River Flow

Operating a dam such as this results in discontinuous flows, and the passage of both flood and stage drop waves downstream. Figures 4.4.1 and 4.4.2 illustrate a portion of the spring of 2013 and 2014, with changes in dam configuration overlain atop measured changes in discharge. Clearly evident is how quickly flow responds at HL-CR-1, typically within an hour flow can more than triple. This flow takes significantly longer to reach downstream, however, due to Marl Lake.

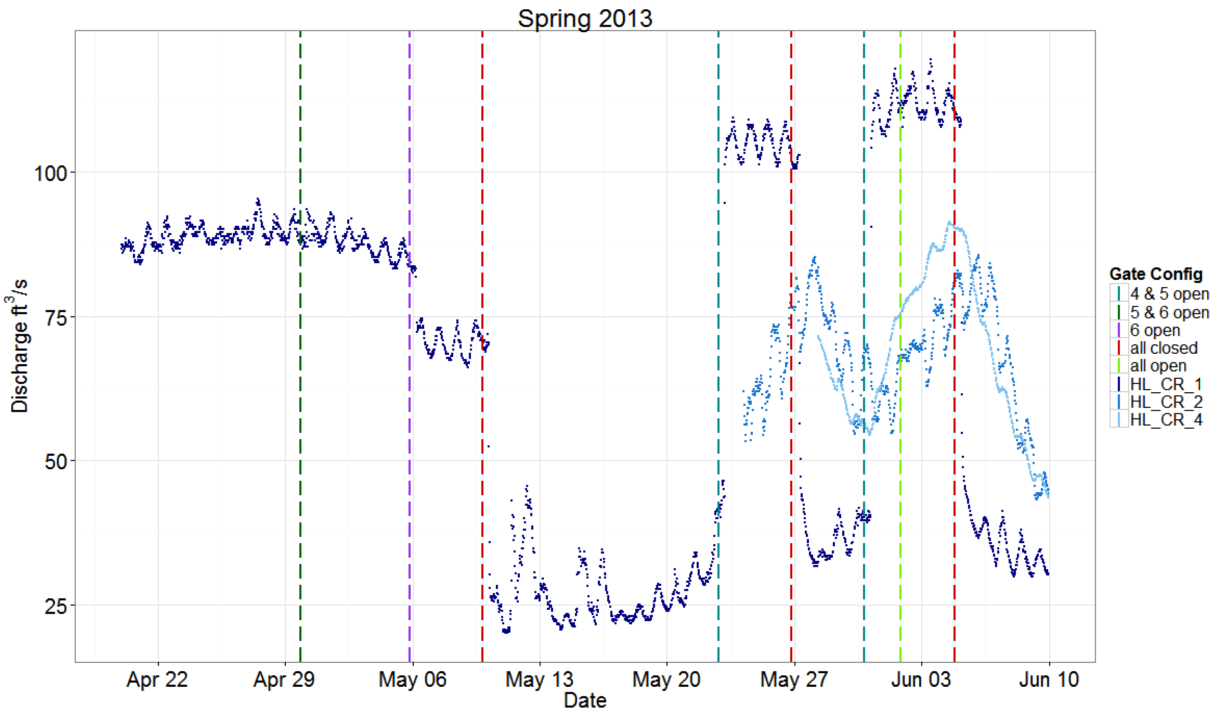


Figure 4.4.1. Plot of rated stream flows at HL-CR-1, 2, and 4 along with dam gate configurations for the Spring of 2013.

The damping effect of Marl Lake can be best seen in May of 2014, in Figure 4.4.2. Two events, first a drop in flows at HL-CR-1 due to dam closure in late April, and then a rise due to dam gate opening in mid-May have a significantly time-lagged impact at HL-CR-4, just downstream of Marl Lake. In general, Marl Lake buffers the response time by nearly two weeks, having both a positive and negative impact on stream flows, but helping to reduce the variability in the flows downstream. In June, following gate closure for the summer, the drop is more rapid, with a buffer of only about one week. This is likely due to reduced groundwater inputs to Marl Lake later in the season.

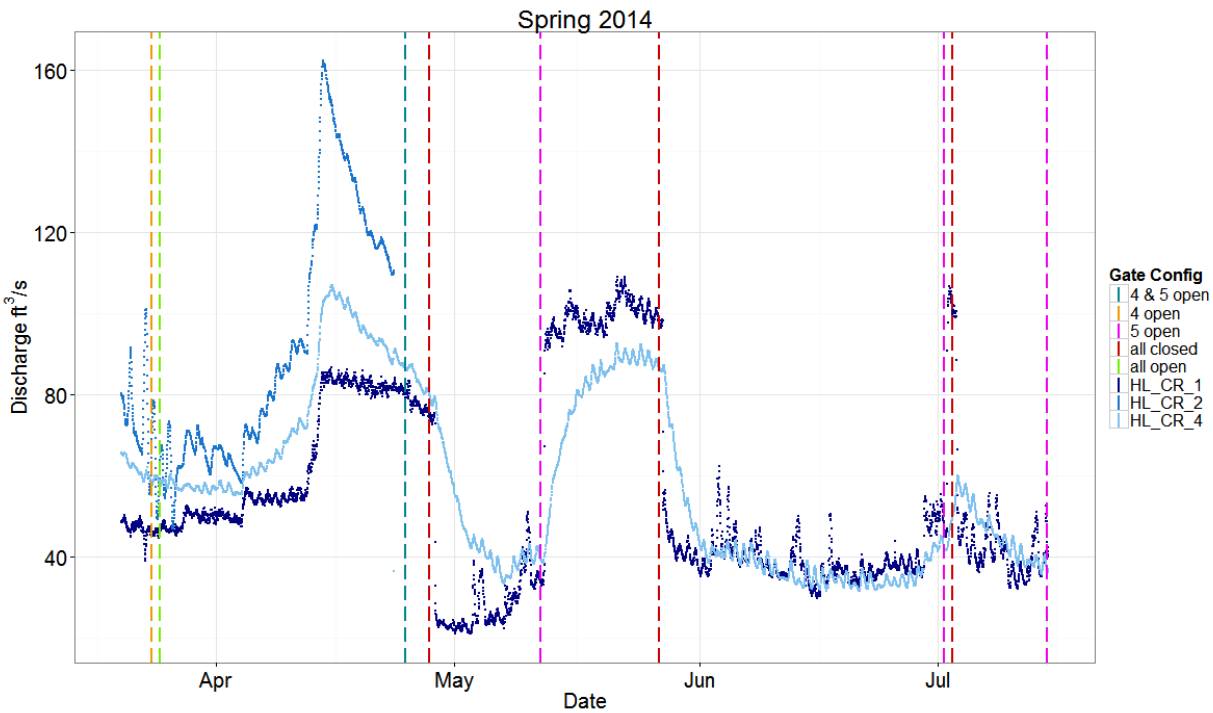


Figure 4.4.2. Plot of rated stream flows at HL-CR-1, 2, and 4 along with dam gate configurations for the Spring of 2014.

Task 4 Findings Summarized

- Water level and temperature was monitored continuously at three locations for nearly three years, with some missing sections, and fourth for approximately two years.
- Good rating curves for each site were developed.
- These data provide further evidence that the Cut River gains relatively little flow for much of the year from groundwater.
- The placement of a gauge just downstream of Marl Lake shows its influence in moderating flows further down the Cut River, particularly during times of rapidly fluctuating flows such as the spring.
- Good dam configuration rating curves will provide managers of the outlet control structure better tools to manage lake levels.

Task 5: Hydrologic Modeling

This task includes applying simulation models to predict the hydrologic (flow and storages of water in the environment) and hydraulic (movement of water in response to pressure gradients) behavior of Higgins Lake, the Cut River, and their watersheds. Specifically, three types of models are applied:

1) HEC-RAS, a hydraulic model that predicts streamflow and stage (height) in actual stream channels in the presence of flow obstructions such as dams, bridges, or culverts for a given input upstream stage.
2) The Landscape Hydrology Model (LHM), an integrated surface and subsurface hydrologic model that predicts water movements across the landscape and through the subsurface through time, in response to climate inputs.
3) A novel water-balance model for Higgins Lake that integrates weather data, historical dam management behavior, and LHM outputs to offer predictions of lake level response to changes in the environment or dam management.

The specific applications of each of these models are detailed in the sections below.

5.1: Hydraulic Modeling of the Cut River Outlet

In Task 5, we have applied HEC-RAS to simulate the flow conditions in the Cut River immediately at the Higgins Lake outlet. The model encompasses a section immediately downstream of the Higgins Lake control structure, through the culverts for East Higgins Lake Drive, and continuing downstream for approximately 1000 feet. The configuration of the model is shown in Figures 5.1.1 and 5.1.2 below. The model was built using GPS-surveyed cross sections, which were then interpolated to a series of more closely spaced virtual cross sections. Dimensions of both the dam outlet and culvert geometries were explicitly measured as well.

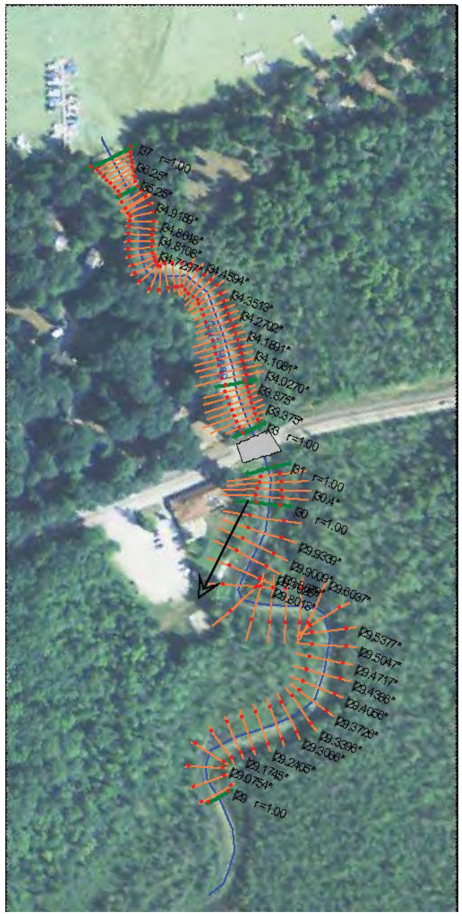


Figure 5.1.1. Overview of the HEC-RAS stream geometry cross sections overlain on a satellite image showing the dimensions and extent of the model. Measured cross-sections are shown in green, while interpolated virtual cross-sections are shown in orange. The culverts under East Higgins Lake Road are indicated as a grey box.

The model was calibrated by adjusting channel and floodplain roughness (a parameter with general value ranges for a specific channel/floodplain type), as well as the degree of sediment build up within the three culverts. The calibration adjusted parameters to better match simulated and observed water levels for flow data we collected at the HL-CR-1 location (immediately upstream of the culverts; See Figure 5.1.3). The calibration successfully captured both the low and higher flow behavior of the stream channel. Additionally, it provided a reasonably robust prediction of the flow behavior of the Higgins Lake outlet section of Cut River under higher flow conditions than those we observed for the creation of our stage/discharge rating curves (Figure 4.2.1).

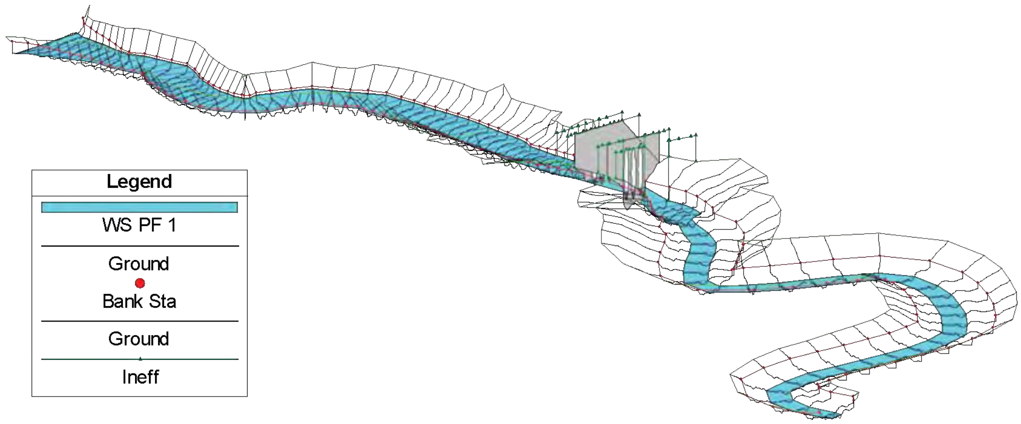


Figure 5.1.2. Three dimensional view of the Cut River outlet HEC-RAS model. The vertical relief in figure was exaggerated by a factor of 30 to more clearly illustrate bank height and channel morphology. The water level shown in blue illustrates a hypothetical minimum discharge of 0.35 cfs before becoming stagnant.

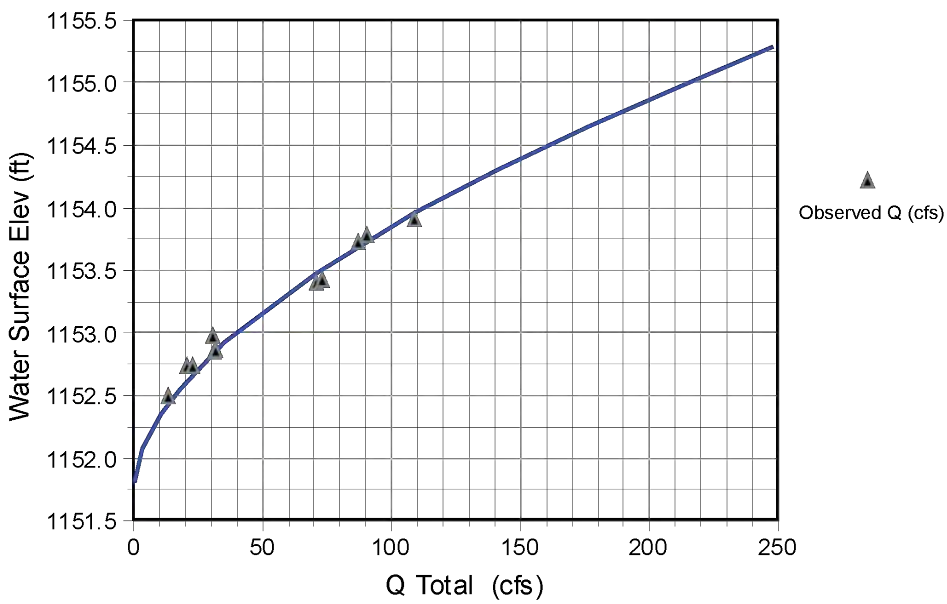
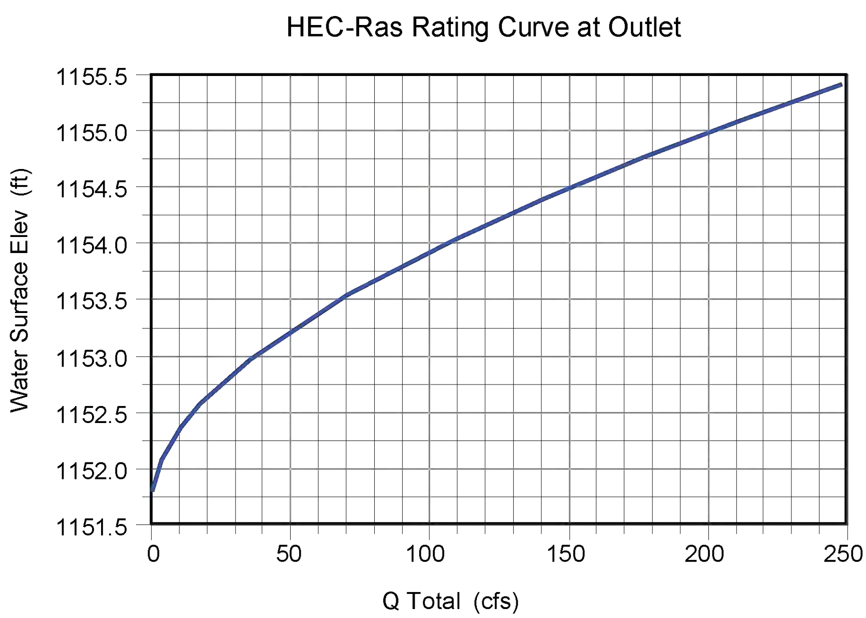


Figure 5.1.3. Rating Curve HEC-Ras Modeled of HL-CR-1. The Hec-Ras Model was calibrated using the observed discharge and water elevation data collected during site visits by MSU personnel.

The primary application of this model was to obtain a prediction of the stage/discharge relationship of this section of the Cut River in the absence of an outlet control structure (the No Dam scenario). The observed stage/discharge rating curves under various dam gate configurations developed within section 4.3 can inform all other lake level scenarios, but the HEC-RAS model is required to understand how the lake will respond were the outlet control dam to be removed.

For this, the farthest upstream cross section in the HEC-RAS model was queried to determine its stage/discharge behavior (Figure 5.1.4). Note the differences between the rating curve for this upstream section and that at the bridge just 750 feet downstream. For instance, at 100 cubic feet per second of flow through the channel, the upstream cross section is at an elevation of ~1153.86 feet (Figure 5.1.4) while for the same flow at the culverts, the stage would be ~1153.80 feet (Figure 5.1.3), a significant difference for lake level predictions where differences in scenarios are on the order of 4 inches, or 0.33 feet.

Figure 5.1.4. Rating Curve HEC-Ras Modeled Immediately downstream of Dam. The rating curve is representative of a non-obstructed outlet from Higgins Lake.



5.2: Lake Groundwater Discharge and Evaporation Predicted with the Landscape Hydrology Model

The Landscape Hydrology Model (LHM) was chosen to simulate the regional hydrology surrounding Higgins Lake. This project leveraged two existing LHM models: one built for an expanded region surrounding the Muskegon River Watershed (EMRW), and another for the Lower Peninsula of Michigan (LPMI). These two model boundaries are shown in Figure 5.2.1 below.

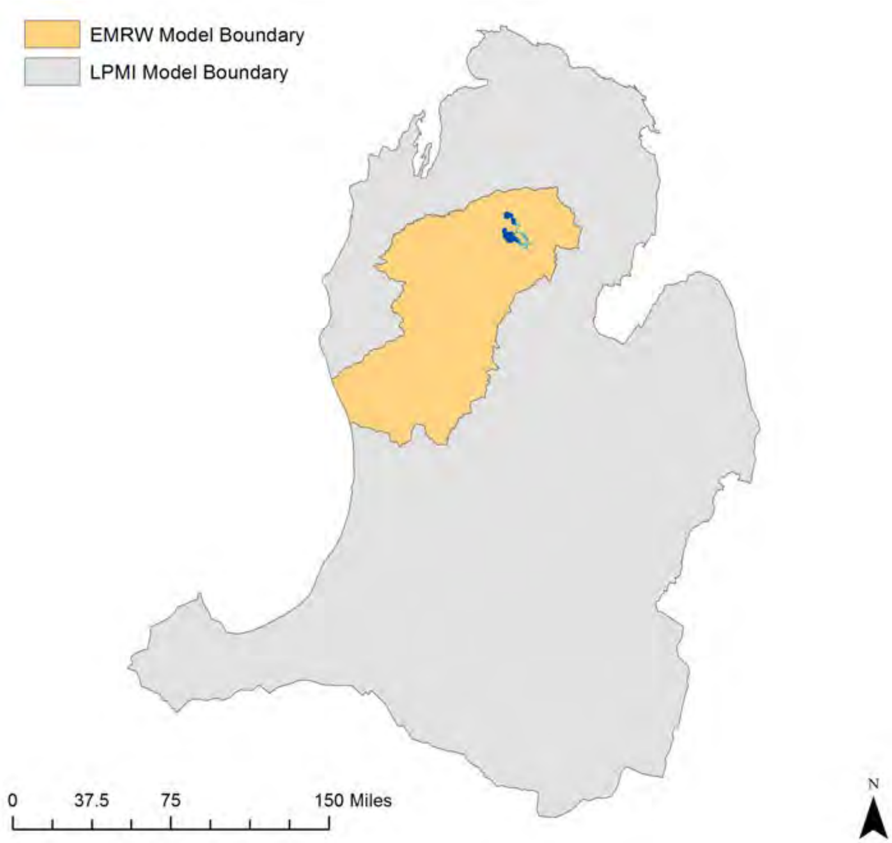


Figure 5.2.1. Map of the EMRW (orange) and LPMI (grey) model boundaries with the Higgins-Cut-Houghton watershed system overlain.

LHM simulates the entire terrestrial hydrologic cycle on an hourly basis, driven by weather data inputs, and parameterized using soil and sediment data from maps, over a region discretized into grid cells. Within each grid cell, equations dictate the movement (or fluxes) and storage of water. This type of model is called a spatially-explicit, process-based model. Figures 5.2.2 and 5.2.3 below illustrate the different components of the water cycle simulated, and how LHM discretizes the landscape.

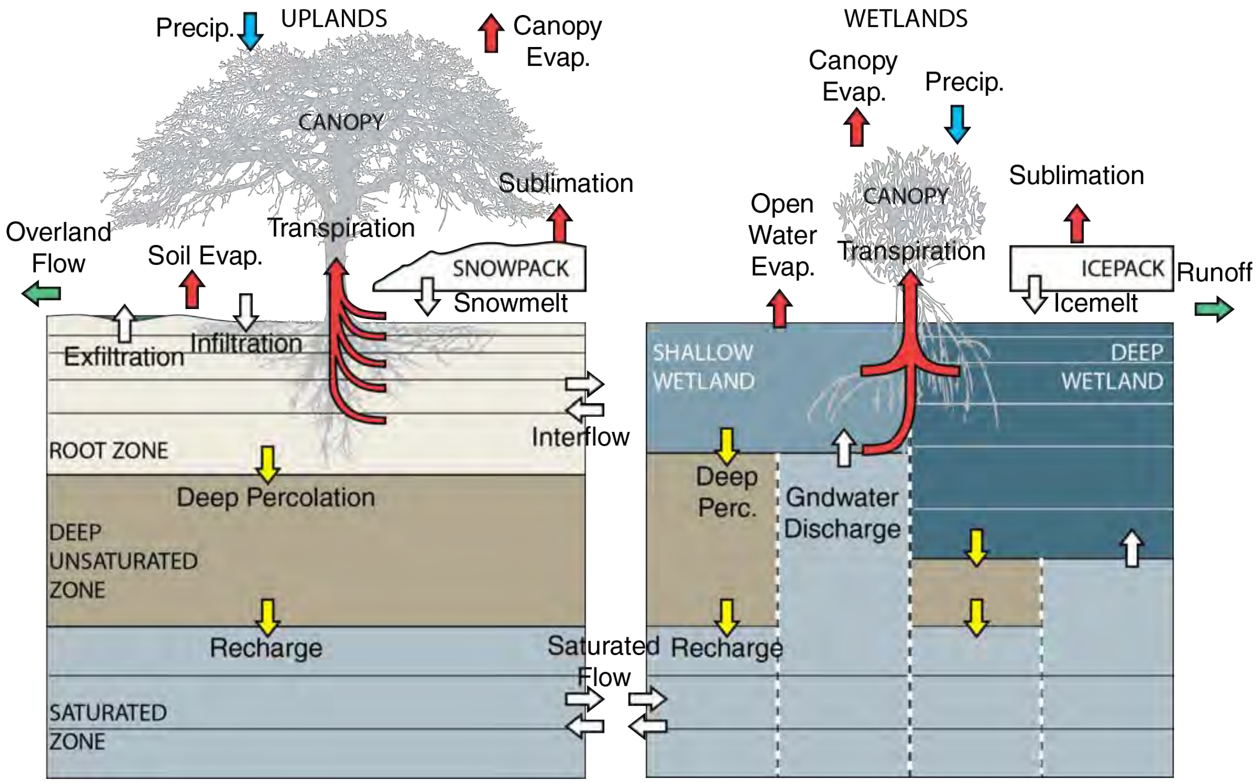


Figure 5.2.2. Conceptual model of hydrologic fluxes simulated by LHM.

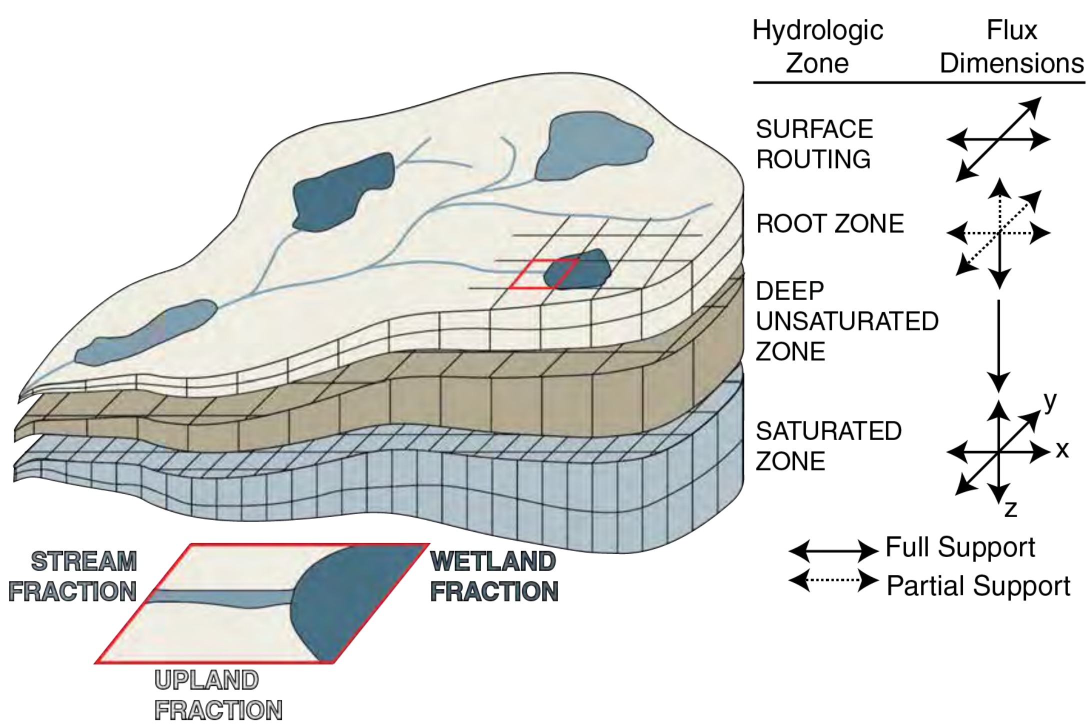


Figure 5.2.3. Conceptual model of the landscape discretization scheme in LHM.

The EMRW model grid cells have a surface resolution of approximately 425 meters on a side, while the groundwater model uses 106 meter cells; the model simulates the 1980 to 2007 period. The LPMI model cells have a surface resolution of 500 meters, and simulates the period of 2000 - 2014. However, the LPMI model does not have a groundwater simulation linked at the time of this report.

This project requires a simulation period similar to the LPMI model, but also a description of groundwater inputs to Higgins Lake for the whole period. The EMRW model has all of the necessary components, but does not extend to 2014. To bridge this gap, we decided on an approach referred to as process-inferred statistical modeling. That is, we used a statistical model to represent the more complex physical processes of the full LHM simulation. We then applied this statistical model to simulate a flux we didn't have (groundwater inputs to Higgins Lake for the full period) using something we do have (groundwater recharge simulated by the LPMI model for that period).

For this approach, simulated groundwater inputs to Higgins Lake (represented in cubic feet per second) for the full 1980 - 2007 period (Figure 5.2.4) were decomposed into two components, annual average inputs (Figure 5.2.5), and monthly average inputs to Higgins Lake (Figure 5.2.6).

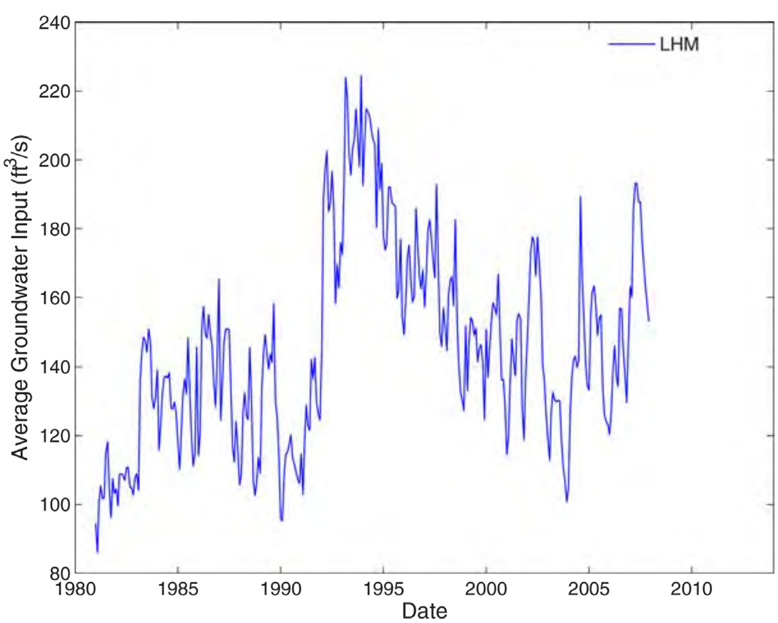


Figure 5.2.4. Monthly LHM-simulated groundwater input (inflow) to Higgins Lake for calendar years 1981 - 2007, expressed in cubic feet per second.

Annually, LHM-simulated average groundwater inputs to Higgins Lake varied between approximately 110 and 210 cubic feet per second, with significant multi-year year cycles. Much of the 1990s decade saw higher inputs than either the 1980s or early 2000s.

To better understand how fluxes into the lake vary by month, Figure 5.2.6 plots inputs as a percent of total annual input--this is essentially the seasonality of input. As expected, fluxes were highest in the spring months following snow melt and prior to the growing season for plants. Also shown as a shaded range is one standard deviation of monthly fluxes, essentially a measure of how much these monthly fluxes varied across years. During the spring, fluxes varied approximately 0.5% of the total input from the mean, while during the late summer and fall this variability increased to as much as 1% of the total annual input. Capturing this variability is important to simulating particularly "wet" or "dry" months in terms of groundwater inputs to the lake.

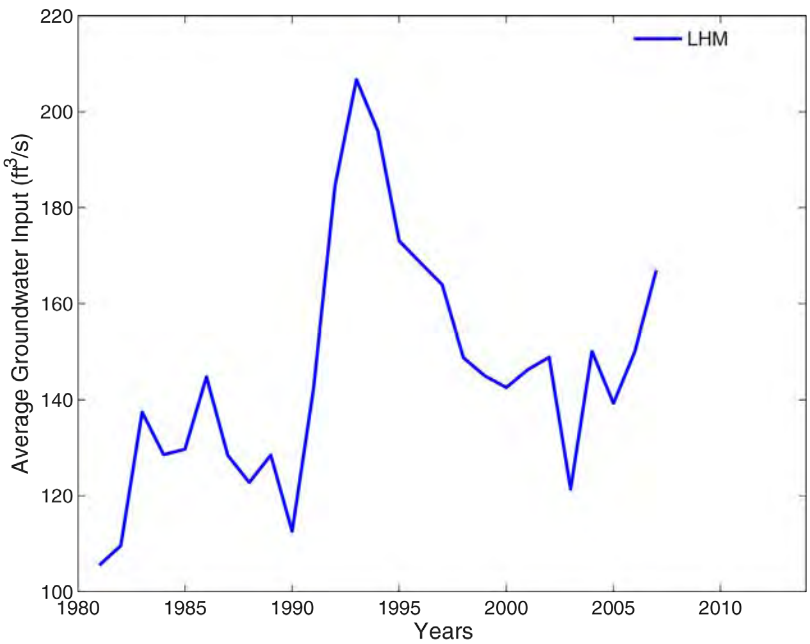


Figure 5.2.5. Plot of LHM-simulated groundwater inputs to Higgins Lake for the calendar years 1981 - 2007, expressed as an average flux rate in cubic feet per second.

Two statistical models were created to describe both the annual total input to the lake, as well as the seasonal cycle of inputs. The annual model is a distributed lag regression model, in which water year (October - September) groundwater recharge within the Higgins Lake *groundwatershed* is summed and used to predict the time lagged calendar year (January - December) groundwater inputs to the lake. This analysis showed that calendar year inputs are sensitive to groundwater recharge up to three water years prior. In other words, according to the LHM simulation of the EMRW, the Higgins Lake groundwater system has a roughly 3 year "memory" of groundwater recharge. Thus, four parameters were used in the regression: current water year groundwater recharge, along with 1-year, 2-year, and 3-year lagged recharge. This statistical model provided a very good fit to annual LHM-predicted values (Figure 5.2.7), with a coefficient of determination (R^2) of 94% (100% would indicate a perfect model fit), and an average error of only 3.4%.

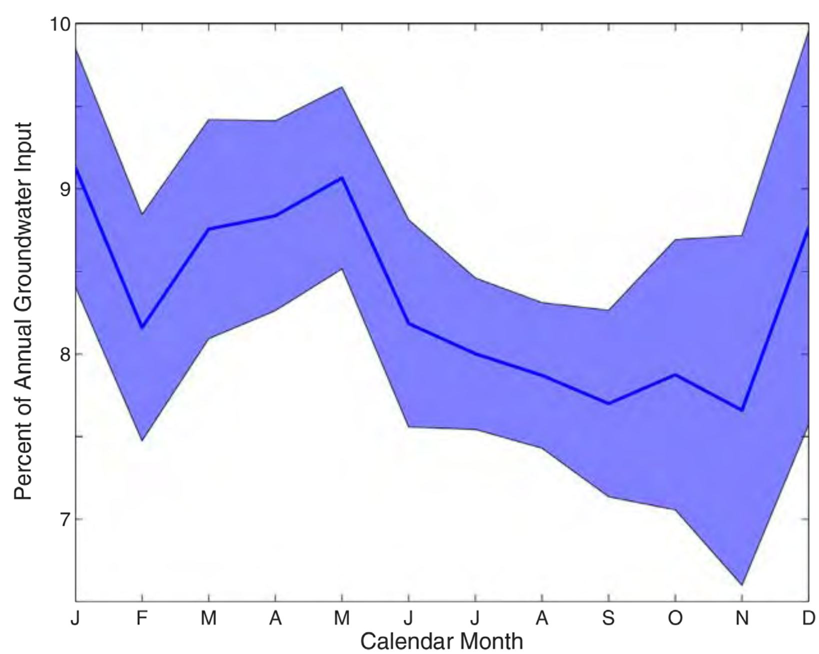


Figure 5.2.6. Plot of monthly averages of model-simulated groundwater input to Higgins Lake from 1980 - 2007 as a percent of annual simulated input. The blue line indicates the mean simulated flow for that month across years, while the shaded area includes +/- 1 standard deviation from the mean.

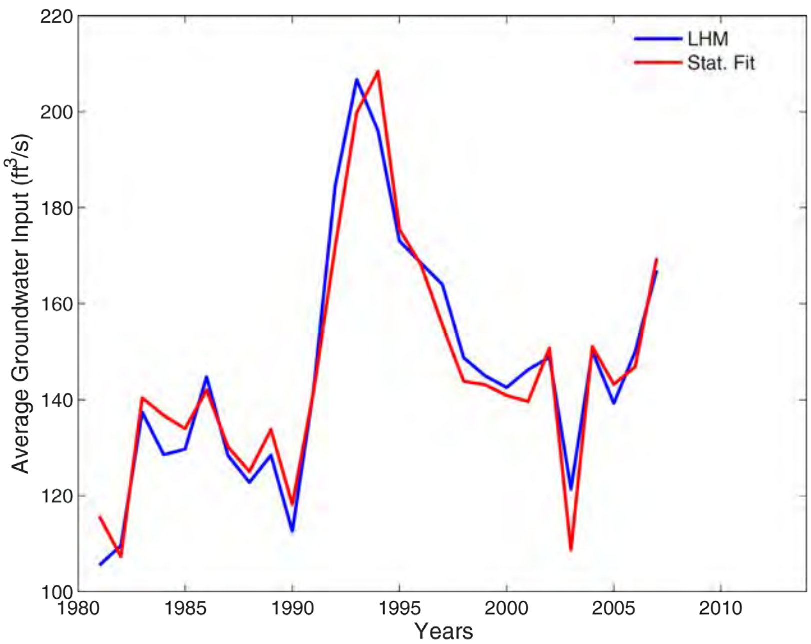


Figure 5.2.7. Plot of LHM-simulated and statistically-fit annual groundwater inputs to Higgins Lake. for the calendar years 1981 - 2007.

Statistically modeling the monthly variability was somewhat more complex. The chosen model structure was to sum the average monthly input to the lake (Figure 5.2.6) and a modeled “anomaly”, or a departure from normal, predicted using LHM-predicted *groundwatershed* recharge. First, annual normal groundwater recharge was calculated for all years. Monthly recharge values were then divided by annual totals to calculate the monthly recharge anomalies relative to normal. This anomaly was then regressed against a similarly-calculated anomaly for LHM-simulated groundwater input to the lake. This allowed for groundwater recharge alone to the predict the anomaly for groundwater input to the lake. This model-predicted anomaly was then added to the average monthly cycle of groundwater input, which was finally multiplied by annual average groundwater input (Figure 5.2.7). The final result is shown in Figure 5.2.8. This model of monthly groundwater input to Higgins Lake is derived solely using LHM-simulated recharge, and compared to LHM-simulated groundwater inputs had an R^2 of 81%, and mean monthly error of 6.7%, and a Nash-Sutcliffe efficiency (a measure of model goodness-of-fit commonly used by hydrologists, with values of 1 meaning a perfect fit, and anything above 0 meaning a model that does better than simply using a single average value) of 0.81.

With the combined annual and monthly statistical models calibrated, they were then applied to calculate annual (Figure 5.2.9) and monthly (Figure 5.2.10) groundwater discharge into Higgins Lake for 2000 - 2014 using only the LPMI simulation of groundwater recharge in the Higgins Lake groundwatershed. The annual model predicting 2000-2014 discharge provided similar predictions to the model fit to 1980 - 2007 discharge, although the monthly model was not quite as accurate. The LPMI and EMRW simulations differ in two key aspects: weather and soils data. These differences mean that the LPMI model predicts a somewhat different seasonal cycle of recharge than does the EMRW model. Nevertheless, the model provided reasonable predictions of the groundwater input on a monthly basis to Higgins Lake.

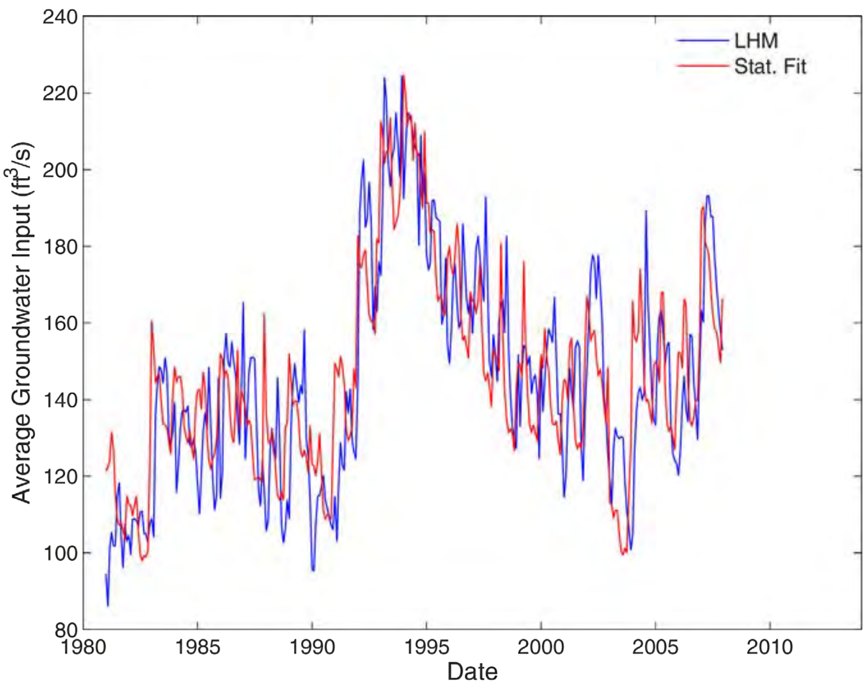


Figure 5.2.8. Plot of LHM-simulated and statistically-fit monthly groundwater inputs to Higgins Lake. for calendar years 1981 - 2007.

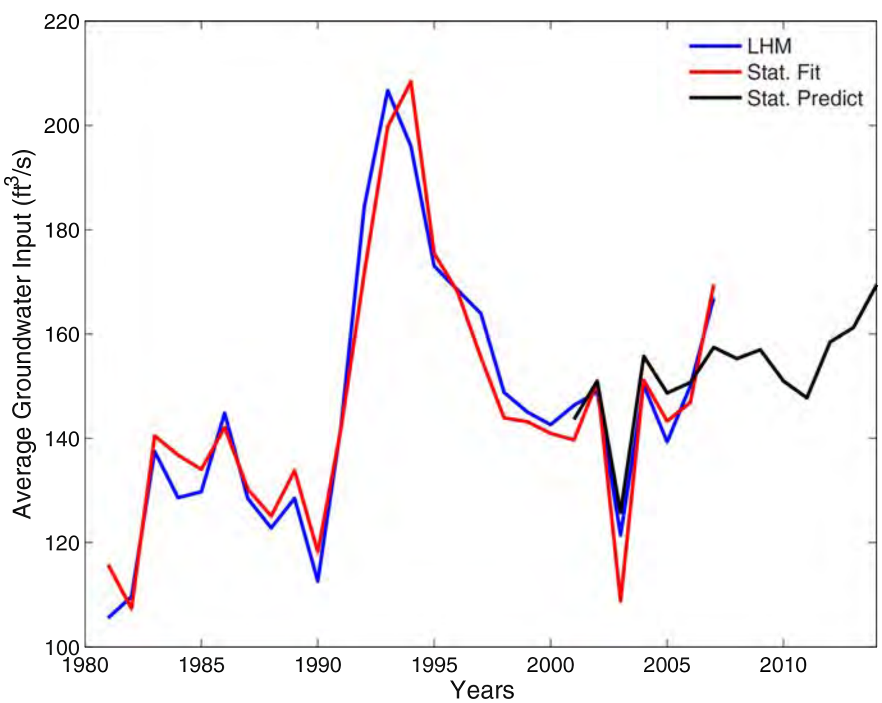


Figure 5.2.9. Plot of annual average groundwater input in cubic feet per second from the Landscape Hydrology Model (blue), a statistical model fit to the LHM prediction (red), and that same statistical model applied to the LPMI simulation results from 2000 - 2014.

Another key simulation component of the overall Higgins Lake water balance is evaporation from the lake. Estimates of lake evaporation are driven by simulated lake temperatures, along with weather inputs including air temperature, wind speed, relative humidity, and solar radiation. It is also affected by the simulated ice cover condition of the lake.

LHM simulates 1-dimensional heat transport within lakes, incorporating the influences of wind-driven convection (circulation of water vertically), density-driven mixing (that drives seasonal stratification and mixing), and lake ice buildup. Temperature is impacted by radiation exchange with the atmosphere (long and short wave, diffuse and direct), sensible heat exchange (direct warming/cooling via the presence and natural convection of warm/cold air above the lake), and latent heat exchange (warming/cooling caused by condensation onto the lake, or evaporation of water from the lake).

Figure 5.2.11 below illustrates air temperature from the NLDAS dataset, averaged over the June - September period of each year. Based on this evaluation, Higgins Lake air temperatures have been experiencing a steady and significant increase in average summer temperature from 1980 - 2015 at a rate of 0.84 degrees F/decade (with a *p* value of <1%).

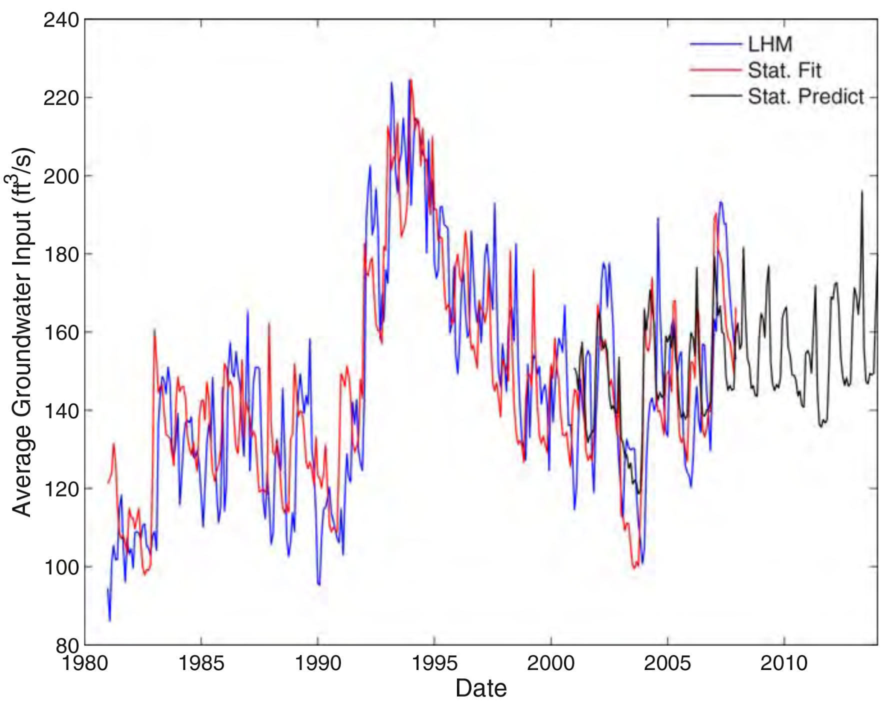


Figure 5.2.10. Plot of monthly average groundwater input in cubic feet per second from the Landscape Hydrology Model (blue), a statistical model fit to the LHM prediction (red), and that same statistical model applied to the LPMI simulation results from 2000 - 2014.

The increase in summer temperature has been a driving force for increased evaporation, as simulated by LHM. Figure 5.2.12 shows annual lake evaporation simulated by the LPMI model for 2000 - 2014. Although the time series is somewhat short for robust trend estimation, there appears to be an increasing trend of evaporation at a rate of 3.79 cubic feet per second/decade (p = 0.15). In general, lake evaporation averages between 17 and 34 cubic feet per second over the course of each year, and can fluctuate greatly between years. This evaporation rate would correspond to an equivalent loss of water from the lake between 14.5 and 28.9 inches each year.

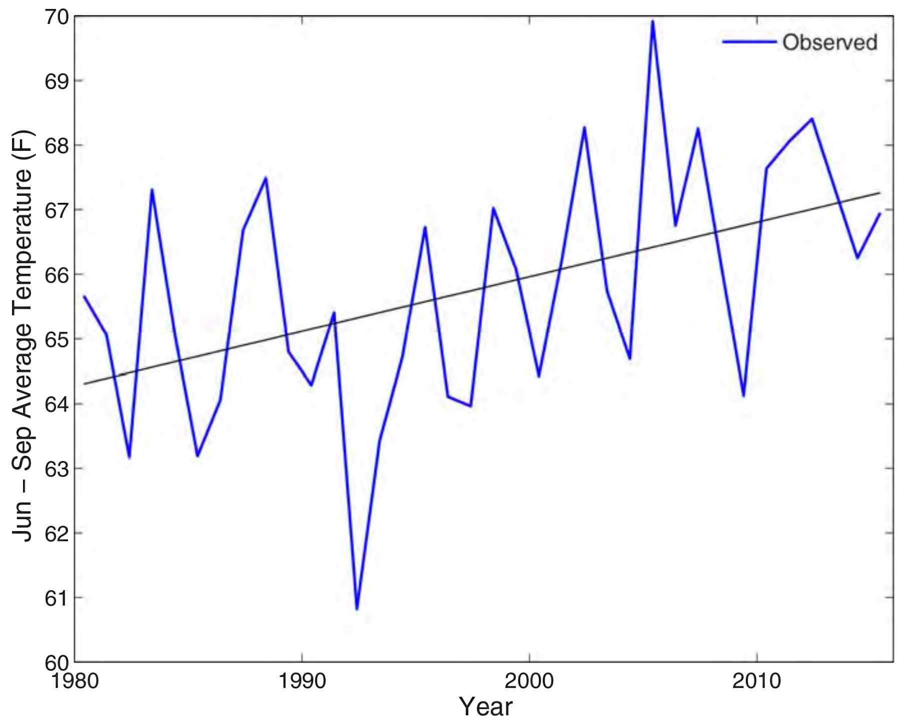


Figure 5.2.11. Plot of June - September average air temperatures over Higgins Lake from 1980 - 2015.

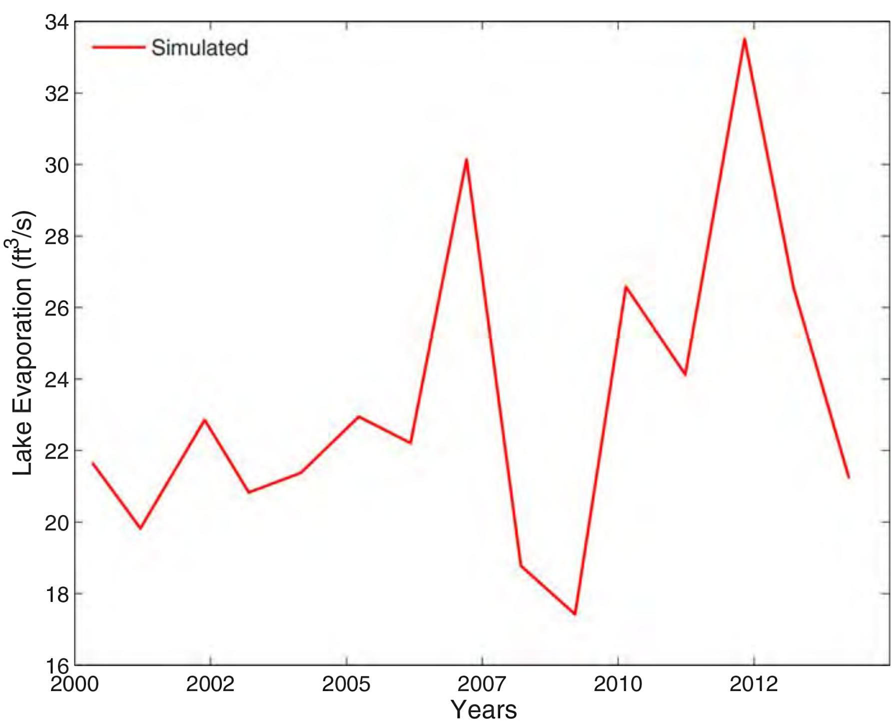


Figure 5.2.12. Plot of simulated annual lake evaporation from 2000 - 2014, in cubic feet per second.

Evaporation is clearly not constant throughout the year, and varies considerably from month-to-month (Figure 5.2.13). During some years (2012, for instance), evaporation rates exceeded 100 cubic feet per second, while simulated evaporation drops to 0 during most winters. In other years, peak evaporation was much lower, such as approximately 50 cubic feet per second in 2009.

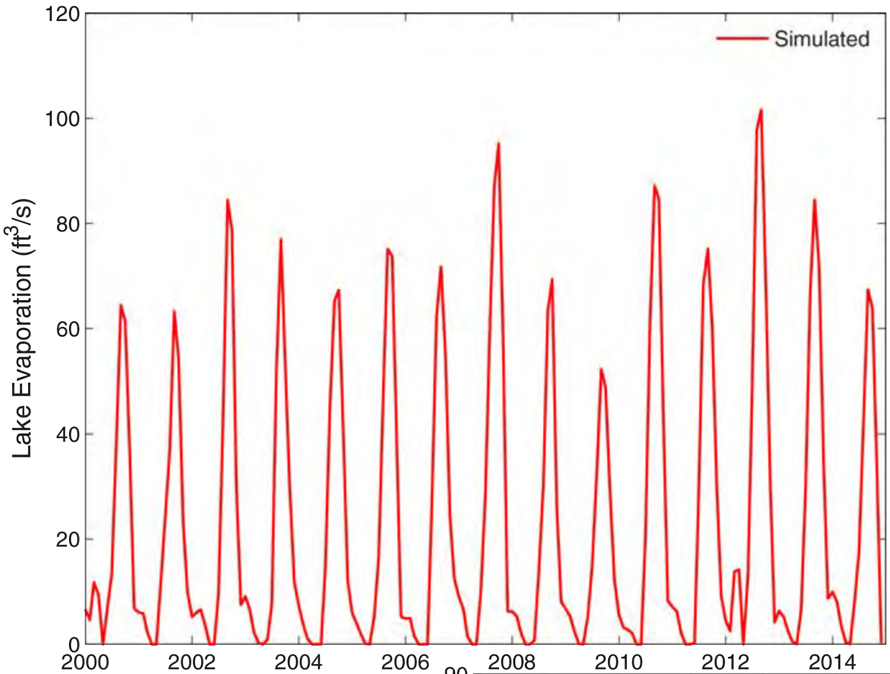


Figure 5.2.13. Plot of simulated monthly lake evaporation from 2000 - 2014, in cubic feet per second.

Averaging across the 15-year LPMI simulation reveals greater detail about the seasonal cycle of evaporation on Higgins Lake.

Contrary to our perception of evaporation rates, large lakes such as Higgins do not peak in the hottest summer months, but rather in September or October, as shown in Figure 5.2.14. Evaporation during peak summer months (June, July, and August) averages between 5 and 50 cubic feet per second. These rates are equivalent to 0.01 - 0.1 inches per day, averaging roughly ½ of the estimate provided by the Spicer group (Task 1.1).

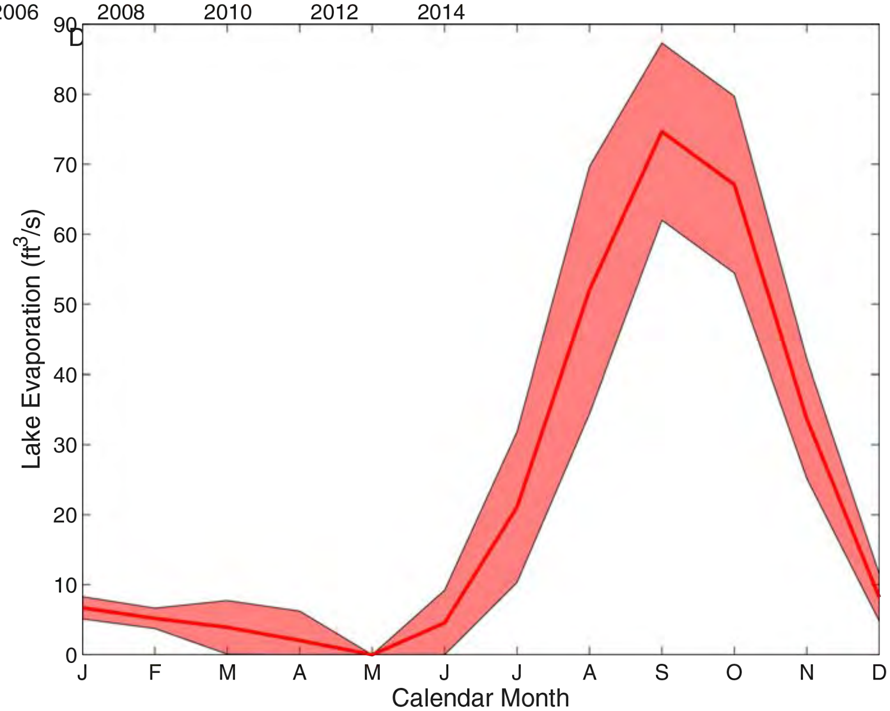


Figure 5.2.14. Plot of simulated monthly lake evaporation cycle, averaged from 2000 - 2014, in cubic feet per second. The shaded region indicates +/-1 standard deviation in monthly input.

5.3: Simulating Lake Levels with a Lake Mass-Balance Model

LHM provides detailed monthly (in fact, hourly, though the data were resampled to monthly periods for this analysis) estimates of critical input and output fluxes for Higgins Lake. To more fully understand what drives lake level dynamics, we first need to construct a conceptual mass balance, which is shown in Figure 5.3.1. For this analysis:

- Precipitation comes from hourly climate data from the National Land Data Assimilation System (NLDAS-2), aggregated daily.
- LHM provides: Surface water inputs, condensation, and evaporation
- The process-inferred statistical modeling described in Task 5.2 provides groundwater inputs
- Outlet flow will be described in this section, using the stage/discharge rating curves developed in 4.3 for the outlet control dam
- Lake storage is known using the gage height data from the USGS
- Groundwater loss will be estimated using what is known as a "residual mass balance approach" described below.

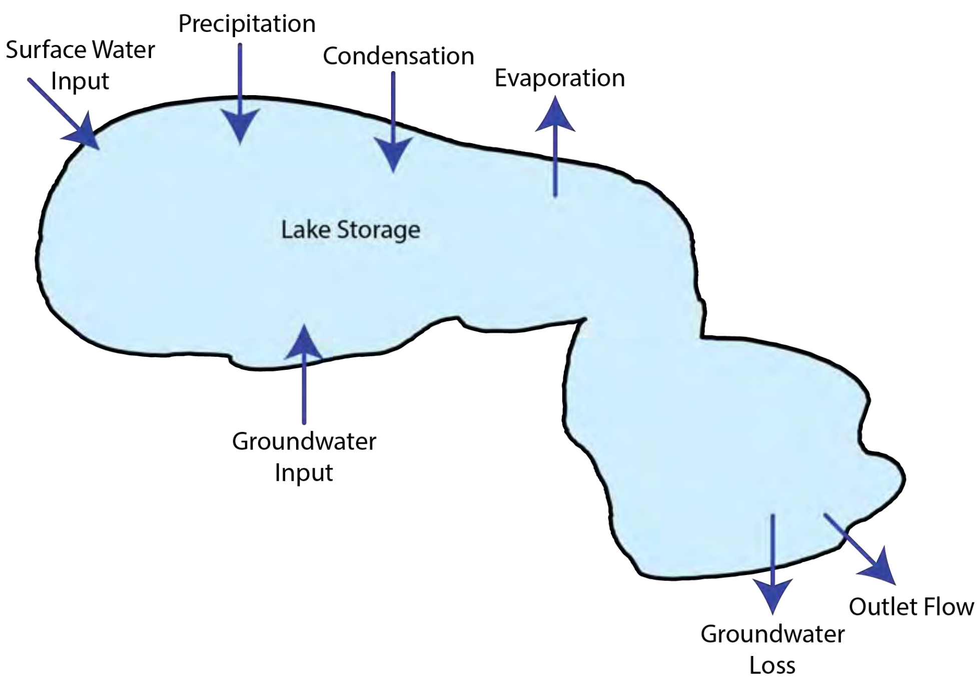


Figure 5.3.1. Conceptual diagram of the mass balance of Higgins Lake.

Represented in equation form, the Higgins Lake Mass Balance is:

$$\Delta S = P + E_{in} - E_{out} + G_{in} - G_{out} \quad + Q_{in} - Q_{out} \qquad \textbf{Equation 1}$$

where: ΔS is Higgins Lake storage, $P$is precipitation, E_{in} is condensation, E_{out} is evaporation, G_{in} is groundwater discharge input to the lake, G_{out} is groundwater loss from the lake, Q_{in} is input streamflow, and Q_{out} is outlet streamflow.

This subtask will first describe the derivation of the outlet stream flow term, then the groundwater loss term. Finally, it will apply these models to simulate change in lake level (storage), and compare this to observed data.

Detailed daily records of Higgins Lake outlet control structure gate configurations have been published in monthly hand-written reports since 2008 and are maintained up to present day. These records describe the open/closed status of the dam's six adjustable gates (flop gates). For this model, three years of those records from 2012 to 2014 were digitized. Those digital records were then used with observed lake elevations during that same period to develop a multinomial logistic regression model that predicts the probability of a particular outcome (all gates closed, 1 open, 2 open, or 3 or more open) versus lake level. Furthermore, separate models were created for the summer (April 15 through October 31st) and winter (November 1st through April 14th) periods. This is because there are separate legally-defined lake level targets for each of these periods, and the dam is managed accordingly.

Figure 5.3.2 plots the winter and summer models. These are somewhat complicated, but are best understood by picking a particular level, and then observing the probabilities of any particular gate configuration being used at that time. For instance, at the two different winter lake levels in use during the 2000-2014 modeling period, the most likely gate configuration is 3 or more open, with probabilities between 72 and 81 percent. As levels drop further, it becomes more likely that only 1 gate would be open. Conversely, during the summer it is far more likely that all gates remain closed, until lake levels are above the legal level, at which point the most likely configuration becomes a single gate open. Very rarely are all three gates open during this period.

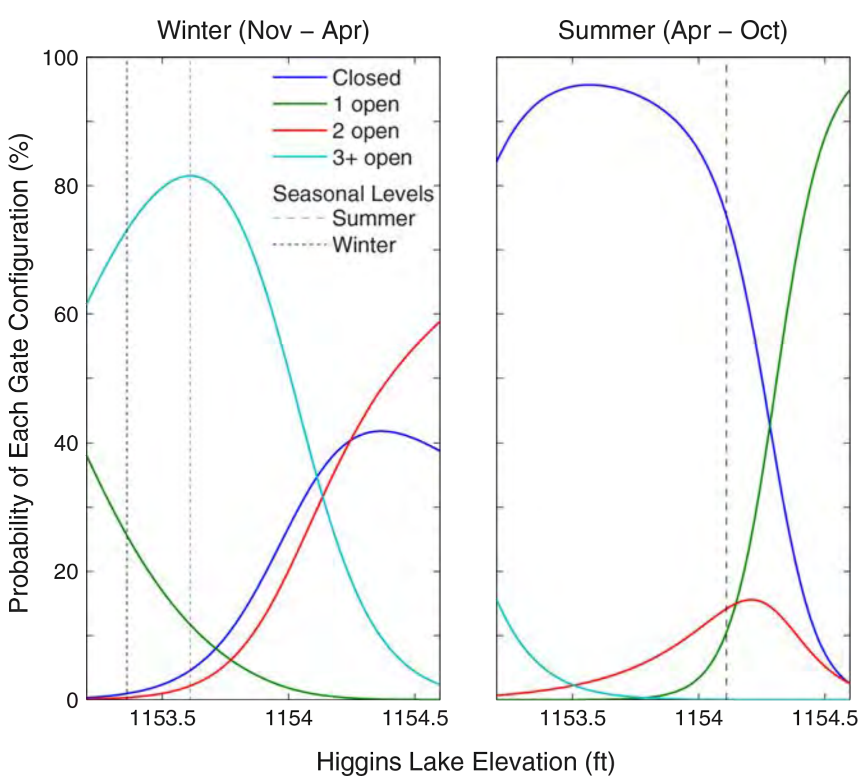


Figure 5.3.2. Plots of the probability of the dam outlet flop gates being in each condition (Closed, 1 gate open, 2 gates open, or 3 or more gates open) versus the lake level on Higgins Lake. Legal lake levels for each season are shown in the corresponding plot, note there are two winter lake levels depending on the year. The Winter and Summer management differs significantly, thus separate models were developed for each season.

Because this model predicts gate configuration with a certain probability, if the model is run 100 times, then 100 different outcomes would occur, though on average the bulk probabilities would match those in Figure 5.3.2. Thus for estimating lake levels and stream outflows, the model was run 100 times in order to better capture the variability in flows/levels that would result from dam management.

The first step in validating this gate configuration model is to compare Cut River outlet streamflow to observed values. This is a two step process: First, observed lake levels for the 2012 - 2014 period and observed gate configurations were used to predict Cut River outflow using the dam configuration rating curves in Figure 4.3.2. These are shown as the red time series in Figure 5.3.3, observed flows at the HL-CR-1 gauge are shown in blue. Second, the observed lake levels from 2000 - 2014 were used with the multinomial logistic regression model to predict gate configurations, which along with the dam rating curves predict outlet discharge. This procedure was repeated 100 times, resulting in the black line (mean) and shaded region (+/- 1 standard deviation) of simulated flow for the entire simulation period.

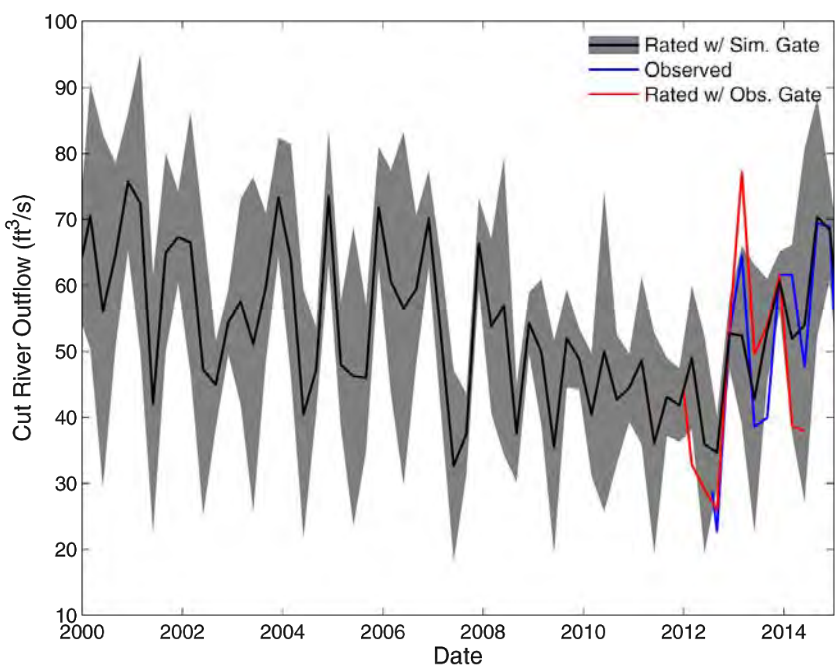


Figure 5.3.3. Plot of seasonal average outflows from Higgins Lake into the Cut River, including observed flows at HL-CR-1 (blue), flows calculated from the dam configuration rating curves above (Figure 4.3.2) and approximately 3 years of digitized dam management records (red), flows calculated using the dam configuration rating curves and a probabilistic simulation of dam gate management (black, with shaded +/-1 standard deviation).

The only remaining unknown quantity in the Higgins Lake Water Balance is then groundwater loss term. This was estimated using a residual mass balance approach. For this, Equation 1 is rearranged:

$$G_{out} = P + E_{in} - E_{out} + G_{in} \quad + Q_{in} - Q_{out} - \Delta S \qquad \textbf{Equation 2}$$

Which allows for groundwater loss to be solved for directly. This approach inherently assumes that the errors across the observed and modeled water balance terms are small. This is, in general, a reasonable assumption. However, groundwater input to Higgins Lake is not directly measurable, and therefore difficult to directly validate. Rather than assuming that this approach yields a direct estimation of groundwater loss, we assume that it also incorporates some error in modeled groundwater input, thus a more accurate representation is:

$$G_{in} - G_{out} = G_{net} = \Delta S - P - E_{in} + E_{out} - Q_{in} + Q_{out} \qquad \textbf{Equation 3}$$

Where G_{net} is net groundwater input to the lake.

Solving for net groundwater input using daily values of the other mass balance terms, and then averaging monthly results in output shown in Figure 5.3.4. This shows that, in general Higgins Lake is a strongly gaining lake from groundwater, but some months it is a net contributor to the groundwater system. Thus the lake is best seen as a groundwater flow through lake.

Physically, this is a reasonable conclusion, given the surface and ground watersheds shown in Figure 1.6.5. The groundwater and surface water sheds of the southeast portion of Higgins Lake extend essentially no further than the lake itself, thus this is very likely a groundwater outflow location.

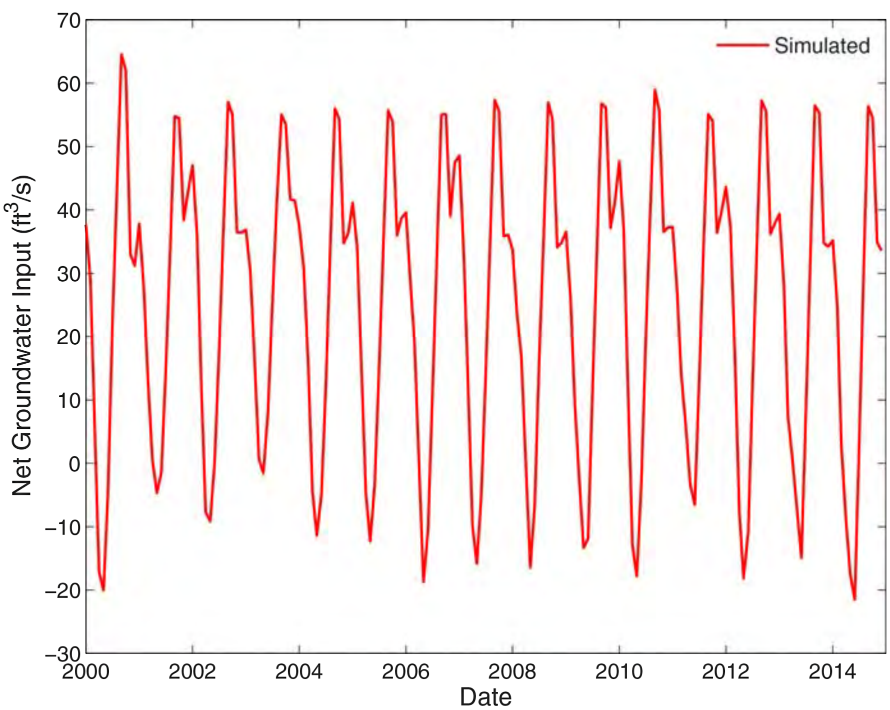


Figure 5.3.4. Simulated net (input - output) groundwater input for the model period 2000 - 2014.

Looking at the simulated net groundwater input on a monthly average basis shows an interesting seasonal cycle (Figure 5.3.5), where from March through May the lake likely contributes water to the regional groundwater system. For the rest of the year, particularly during high evaporation periods in September - October, the lake is strongly gaining on the whole. The lake also gains significantly during the winter.

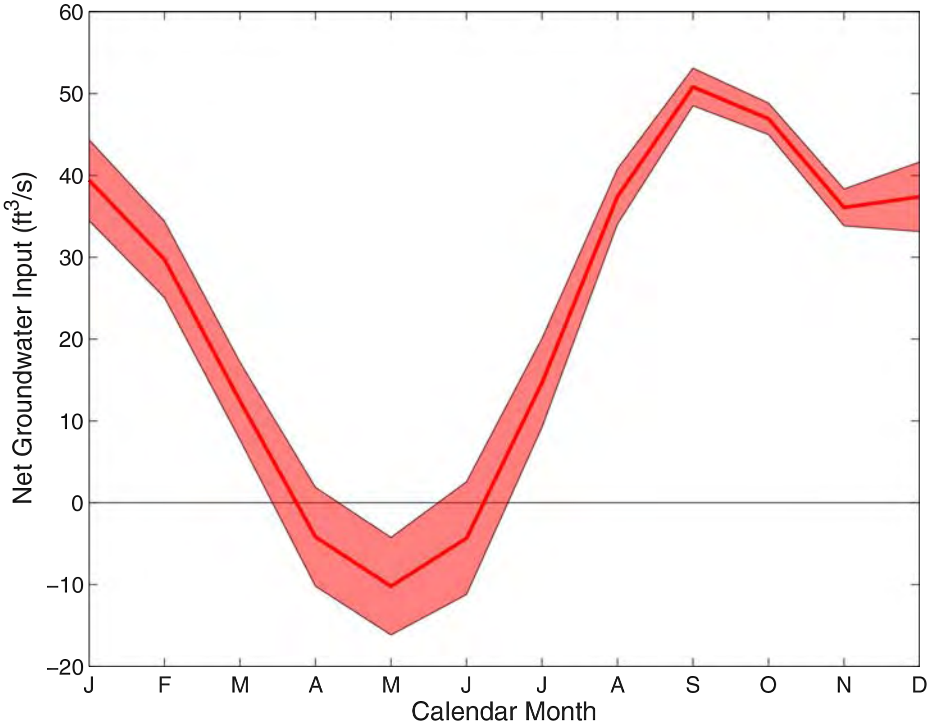


Figure 5.3.5. Simulated monthly net (input - output) groundwater input averaged over the model period 2000 - 2014. The shaded region indicates +/-1 standard deviation in monthly input.

With all terms of the lake mass balance known, we can return to Equation 1, and use the model to predict change in storage (lake level) in Higgins Lake, and compare the model's behavior to observed lake levels. The model simulates daily changes in lake level, based on the inputs from LHM and climate, then simulates statistical dam configuration using the models developed in this section, which provides a dynamic outlet flow response. The model was run 100 times to better capture the probabilistic behavior of dam management. The output of this is shown in Figure 5.3.6.

In general, the model does a good job of capturing lake level dynamics, some years matching behavior very well, while in others the peak and trough levels are not accurately matched. For the 2000 - 2014 period, the model had a mean absolute error of 1.61 inches in level, and an R^2 of 50%, with a Nash Sutcliffe Efficiency of 0.36. Overall, this is a good model with significant predictive power.

Since the model was calibrated to dam management during a period of lower winter lake level targets (as this was the only digital management data available), it is likely to underpredict winter levels. However, the model still provided good results in general.

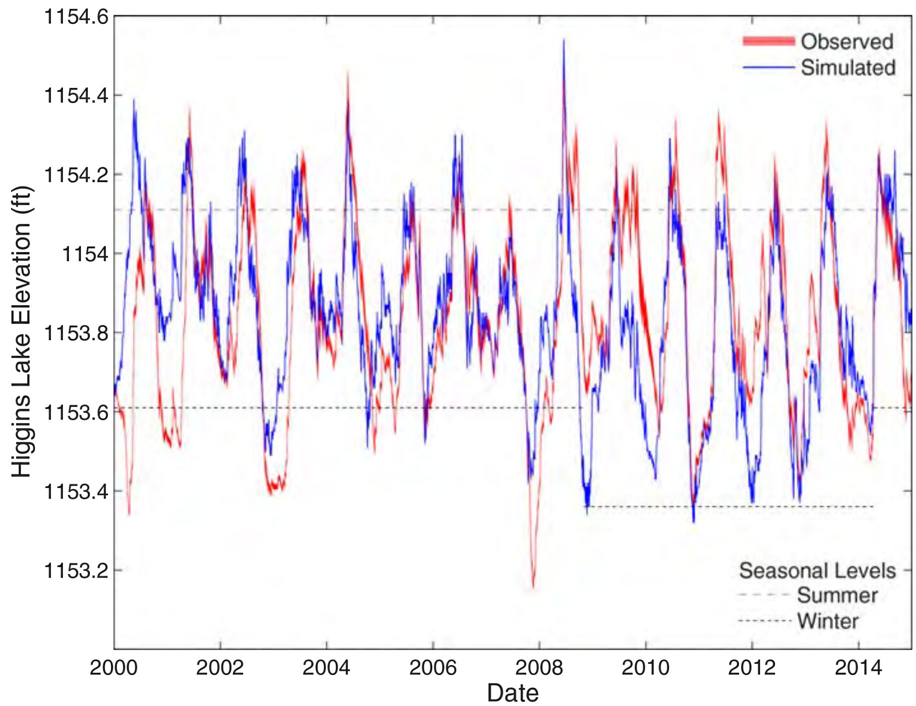


Figure 5.3.6. Plot of simulated and observed Higgins Lake elevations in feet for the period 2000 - 2014. Barely visible are the +/- 1 standard deviation of simulated levels for the 100 simulation runs.

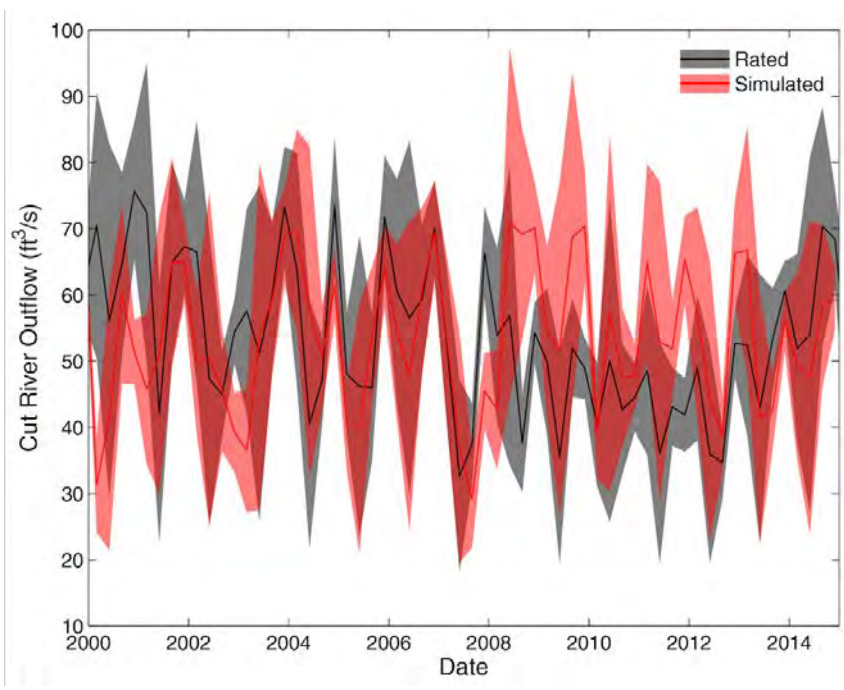


Figure 5.3.7. Plot of seasonal Cut River outflows from Higgins Lake using the dam configuration rating curves and the dam management model (Rated) along with outflow predicted using simulated lake levels and the dam management model (Simulated).

Finally, given the simulated lake levels, dynamically predicted outflows were plotted against outflows predicted using observed lake levels (Figure 5.3.7). In general, the models agree within a single standard deviation in monthly outflows. However, some years, 2008-2009 in particular, the dynamic lake level model overpredicts Cut River outflows.

5.4: Evaluation of Lake Level Scenarios with Mass Balance Model

The full suite of models can then be applied to simulate Higgins Lake levels in response to altered dam management, or hypothetically speaking dam removal. This section investigates two such change scenarios, in which: 1) the dam is left fully open at all times, but remains in place, and 2) where the dam is removed. The first scenario is evaluated by foregoing the dam management model and setting the gate configuration as all open. The second scenario removes both the dam management model and the dam configuration rating curves, and represents Higgins Lake outflows using the HEC-RAS outputs shown in Figure 5.1.4.

These scenarios are overlain with the current management simulation in Figure 5.4.1. As expected, simulated levels are lower for both scenarios, with peaks not reaching the same elevations, and troughs lower than under current management. However, it is also clear that the change in levels is not as large as was expected during the initial development of the lake level scenarios. Because the sill of the the outlet control structure is approximately 18 inches below legal lake level, we originally assumed that this would be the level to which summer lake levels could reach, however this never occurred. Nor did the 20 inch lowering which we considered possible with dam removal occur in our simulated scenarios.

Figure 5.4.2 plots the monthly differences between the two alternate scenarios and current lake level management. In general, the always open scenario oscillates between 6.5 and 0.5 inches below current levels on an annual basis, while the no dam scenario exhibits roughly the same pattern, but between 10 and 4 inches below current levels. The no dam scenario shows a greater degree of variability in differences from current.

Figure 5.4.3 plots the daily lake levels as a probability of occurrence, with winter and summer levels split out separately. Somewhat surprisingly, winter levels are not strongly impacted by the dam open scenario, but are more affected in the no dam scenario. Summer levels show that the dam always open scenario results in about the same lowering relative to current management as does the dam removal relative to the dam open scenario. The lowest lake level in all scenarios was approximately 18 inches below the current legal summer level, and had a very low probability of occurrence < 1%. Thus, the 18 inch drop scenarios considered in Task 2.3 should be considered highly improbable for the summer, and the 20 inch drop essentially not possible.

In fact, this model likely overstates the lower levels because it does not dynamically adjust for the increases in groundwater inputs that would occur with lower groundwater levels. As lake levels decline so would groundwater loss, and groundwater gain would increase, thus the estimates shown here should be considered pessimistic in terms of lake level declines for these scenarios.

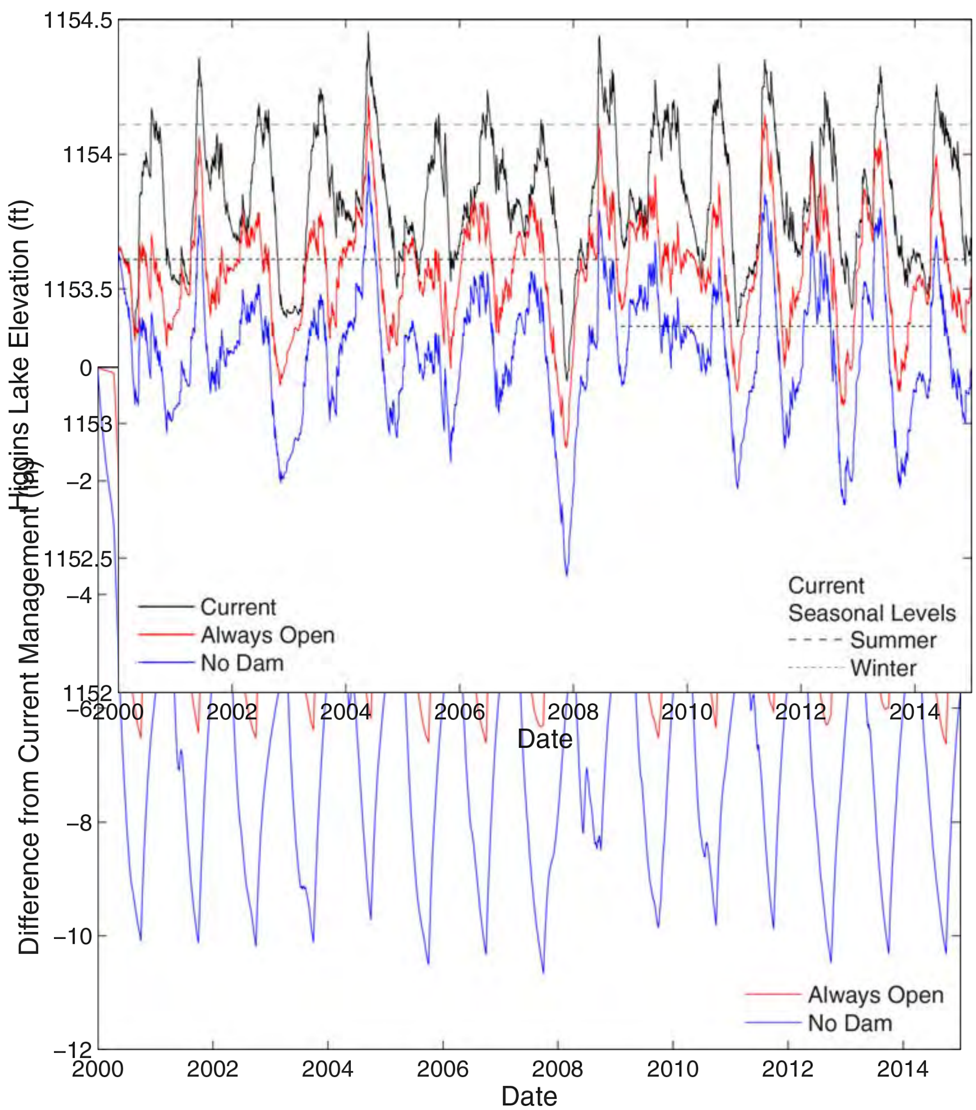


Figure 5.4.1. Plot of daily lake levels simulated by the Higgins Lake Water Balance model for the simulation period 2000-2014. Three scenarios are shown: 1) Current management of the dam, 2) Leaving the dam fully open at all times, and 3) Removing the dam.

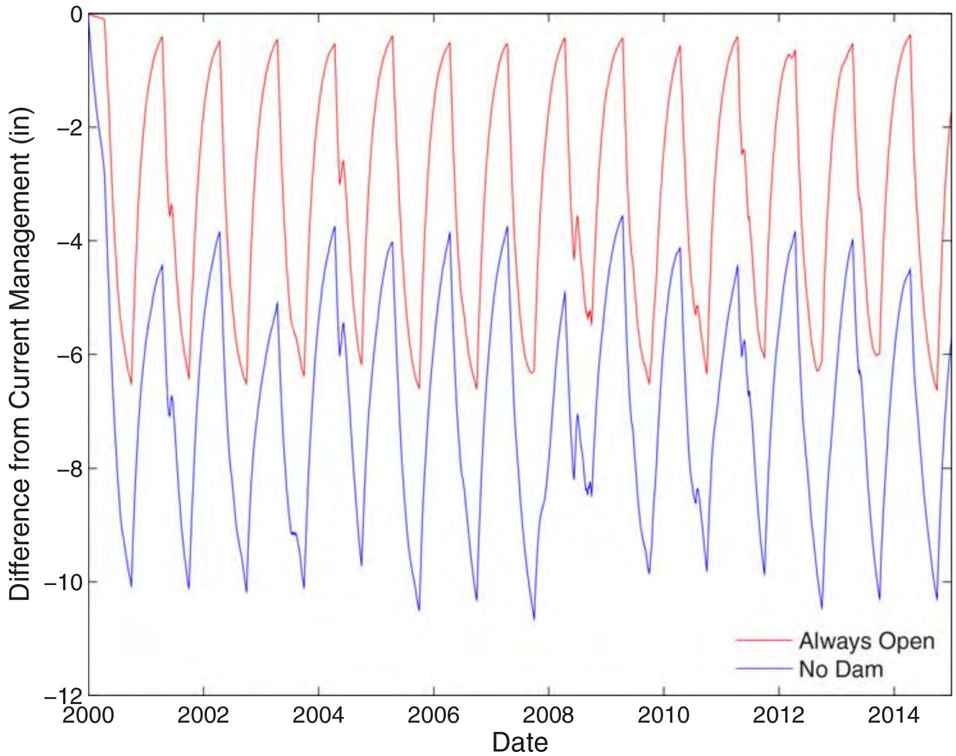


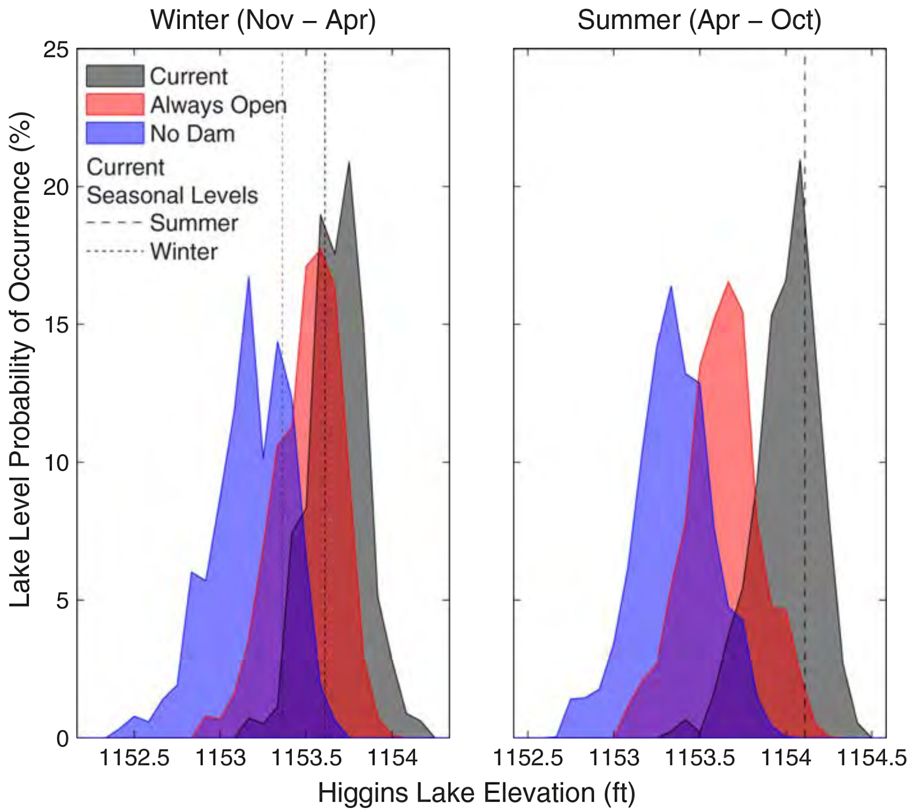
Figure 5.4.2. Plot of the monthly differences between current dam management and the two alternate dam scenarios, in inches.

Perhaps most importantly for recreational and ecological lake uses, the mean summer and winter lake level changes for the two scenarios are shown relative to current management in Table 5.4.1. During winter, levels were an average of 2.4 inches lower in the always open scenario, and 6 inches lower in the no dam scenario. During summer, levels were on average 4.8 inches lower in the always open scenario, and 8.4 inches lower in the no dam scenario. As was mentioned above in Task 2.3, this is why these two scenarios were chosen to present the spatial impacts of lake level changes on intermediate dock length, and final shoreline position.

Table 5.4.1. Average (mean) lake levels during the summer and winter periods for each of the three simulated lake level scenarios. Units are in feet of elevation.

Dam Scenario	Winter (elev. ft)	Summer (elev. ft)
Current	1153.7	1154.0
Always Open	1153.5 (2.4 inches lower)	1153.6 (4.8 inches lower)
No Dam	1153.2 (6 inches lower)	1153.3 (8.4 inches lower)

Figure 5.4.3. Histograms of summer and winter lake levels averaged across the 2000 - 2014 daily water balance model for each of the three dam management scenarios. Both winter legal levels are plotted in dotted vertical lines, and the summer in dashed vertical. Histogram bins are 1 inch, thus the vertical axis can be used to infer the probability of each 1-inch bin occurring under each scenario.



Altering dam management will also impact flows on the Cut River, which are plotted as histograms of daily values in the summer and winter separately in Figure 5.4.4. Note that the two dam management change scenarios have essentially the same probabilities, which is expected because the level of the outlet within such a small margin has little impact on flows--only active management will create seasonal storage. Indeed, the summer flows under the unmanaged scenarios are significantly higher, approximately 25 cubic feet per second, whereas winter flows are lower by a somewhat smaller margin.

Critically from an ecological perspective, the unmanaged dam scenarios keep flows within a 50 cfs target range for most of the year, which is highlighted in the ecological impacts report on Task 6.

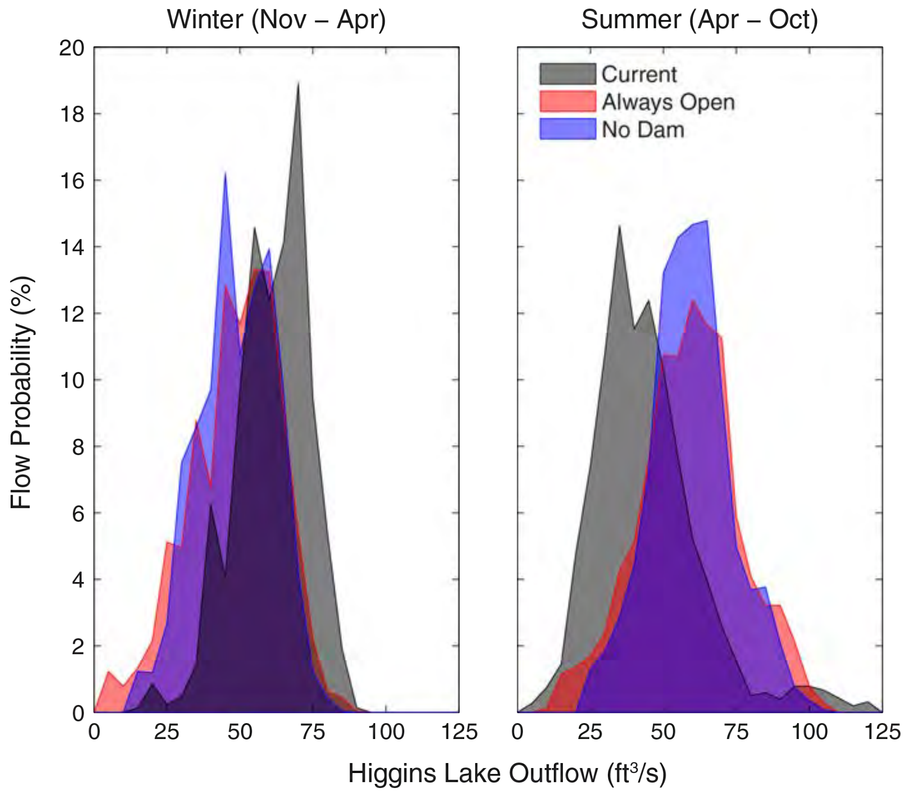


Figure 5.4.4. Histograms of summer and winter Higgins Lake Outflow through the Cut River for the three scenarios. Histogram bins are 5 cubic feet per second, thus the vertical axis can be used to infer the probability of each 5-cfs bin occurring under each scenario.

Task 5 Findings Summarized

- A suite of hydraulic (HEC-RAS), hydrologic (LHM), and statistical models (groundwater input and dam management) were used to calculate the terms of a dynamic lake level model.
- This lake level model produced reasonable daily estimates of Higgins Lake levels, within 1.6 inches of the actual observed level on average.
- Two scenarios, in which the dam is left open at all times, and where the dam is theoretically removed, were investigated with the dynamic lake level model.
- Mean changes in summer lake levels were 4.8 inches lower for the always open scenario, and 8.4 inches lower for the no dam scenario.
- These level changes are much smaller than would be expected assuming that the lake would drop to the lowest elevation of the current dam (18 inches below current summer level), or the lake outlet bottom (20 inches below current summer level).
- This dynamic lake level model likely over predicts level declines, due to the lack of a feedback with the groundwater system that would occur in reality.
- The level drop scenarios with changes greater than 9 inches thus represent increasingly unlikely scenarios, with essentially no chance of the 18 or 20 inch drop scenarios occurring.
- Cut River outflows from Higgins Lake are enhanced during the summer in the unmanaged scenarios, reaching 50 cfs for most of the summer (and winter as well).

Task 7: Survey of Higgins Lake Landowner Concerns

In this task we briefly summarize the results from a local residents survey conducted by Huron Pines, a project partner. The survey lists the top 5 concerns of respondents coded into 12 categories. Notably, boating, beach use, and water quality were the top three concerns of respondents.

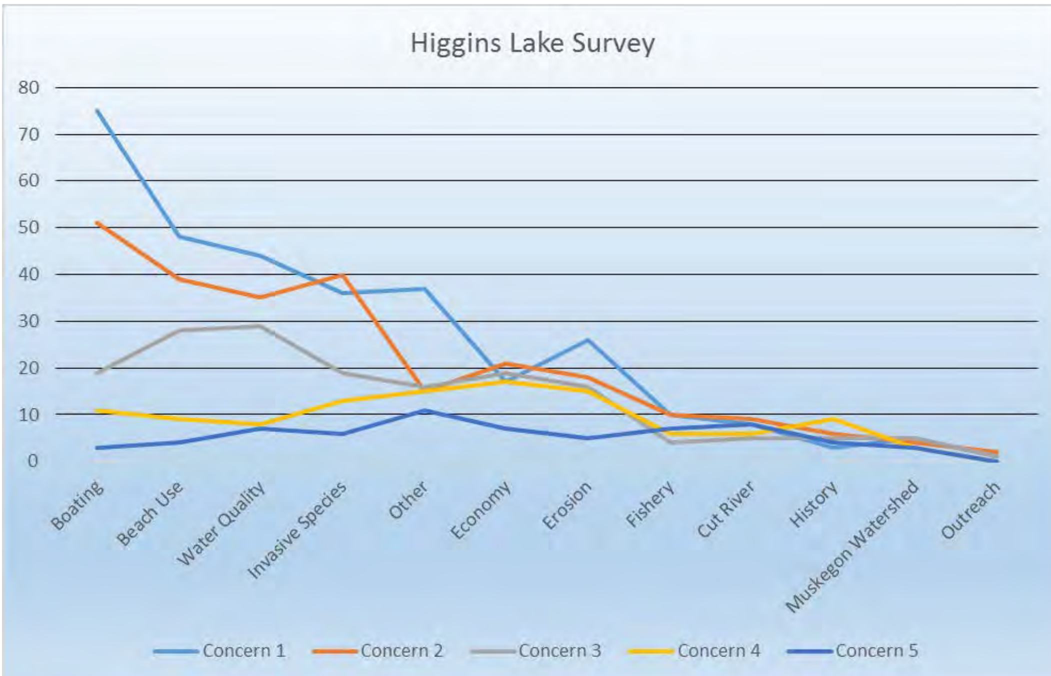


Figure 7.1. Plot of survey responses grouped into broadly-defined categories. Numbers of responders indicating each category is plotted, line colors denote the order of concern listed, from most important (Concern 1) to least important (Concern 5).

Conclusions

The key findings from each of the Tasks 1-5 are detailed in subsections above. Most significant among them are that:

- A state-of-the-art hydrologic study has been completed that provides Higgins Lake area residents, dam managers, and state regulators with an unprecedented view of the lake.
- No credible evidence of significantly lower lake levels or outlet position/configurations in recent (post-settlement) history was found
- Strong evidence for active shoreline erosion was observed at many locations around the lake.
- This study produced a series of outputs that will benefit managers, conservation groups, residents, and researchers.
- The new bathymetric map produced by this study provides the detail needed to assess potential changes in shoreline, dredging, and dock lengths due to lake level changes
- The first continuous multi-year and longitudinal flow datasets have been collected for the Cut River, which highlight:
    - The role of Higgins Lake in maintaining flows on the Cut River, and
    - The relatively minor role that management of the control structure at the outlet of Higgins Lake plays in determining Houghton Lake inputs downstream, except in short periods when gates are opened.
- Dynamic lake level modeling has shown that even with drastically altered dam management, or even fully removing the dam, lake levels are unlikely to drop more than 9 inches on average during summer months.
- Scenarios in which the dam is either left open or removed lead to higher summer outflows and somewhat lower winter outflows, which may be of ecological importance (see Task 6 report).

References

Kraus, N. C. 1988 "The effects of seawalls on the beach: an extended literature review." *Journal of Coastal Research* Special Issue No. 4, p 1-28.

Kriesel, W., and Friedman, R., 2003, "Coping with coastal erosion—Evidence for community-wide impacts", *Shore and Beach*, v. 71, no. 3, p. 19–23.

Phillips, B., and Rasid, H., 1996, "Impact of Lake Level Regulation on Shoreline Erosion and Shore Property Hazards: The Binational Case Experience of Lake of The Woods", *The Great Lakes Geographer*, v. 3, no.2, p. 11-28.

Appendix A

Cumulative Probability of Outflow During Summer, Table

Flow(cfs)	Prob_Curr(%)	Prob_Open(%)	Prob_NoDam(%)
5	0.235294	0	0
10	1.01961	0.117647	0
15	2.54902	1.2549	0
20	7.17647	2.62745	0
25	14.2745	4.31373	1.29412
30	25.9608	6.70588	3.13725
35	40.1176	10.9804	6
40	51.7255	16.0784	10.4314
45	62.902	23.6863	17.7255
50	74.3137	34.4314	30.9412
55	82.2353	45.1373	45.2157
60	87.2157	57.5294	59.8824
65	91.2941	69.1765	74.6667
70	93.8431	80.4314	84.3137
75	95.098	86.3137	89.2941
80	95.9608	90.3922	92.9804
85	96.5098	93.6078	96.7451
90	96.9412	96.8235	98.8235
95	97.6863	98.9412	99.5686
100	98.1569	99.7255	99.9216
105	99.0196	100	100
110	99.5294	100	100
115	99.7255	100	100

120	100	100	100

Appendix B

Cumulative Probability of Outflow During Winter, Table

Flow(cfs)	Prob_Curr(%)	Prob_Open(%)	Prob_NoDam(%)
5	0	1.22909	0
10	0	2.01434	0
15	0.273131	3.34585	1.22909
20	0.990099	5.49676	2.42404
25	1.26323	10.618	5.08706
30	1.67293	15.5685	12.5982
35	3.10686	24.3428	21.1676
40	9.49129	31.1369	30.8638
45	13.3834	43.9399	47.0809
50	23.0113	55.6163	57.8354
55	37.2482	68.9314	70.6043
60	50.2561	82.1782	84.534
65	64.6637	91.2598	94.1618
70	82.7586	96.6541	98.3271
75	92.1475	98.8733	99.522
80	97.6784	99.522	99.9659
85	99.8976	99.9659	100
90	100	100	100
95	100	100	100
100	100	100	100

105	100	100	100
110	100	100	100
115	100	100	100
120	100	100	100

Appendix C

Cumulative Probability of Lake Levels During Summer, Table

Level(ft)	Prob_Curr(%)	Prob_Open(%)	Prob_NoDam(%)
1152.5	0	0	0
1152.58	0	0	0
1152.67	0	0	0.588235
1152.75	0	0	2.11765
1152.83	0	0	3.52941
1152.92	0	0	6.19608
1153	0	0.392157	10.4706
1153.08	0	2.27451	18.0392
1153.17	0	4.23529	31.6078
1153.25	0	7.92157	46.0784
1153.33	0.27451	14	60.6275
1153.42	1.01961	24.6667	75.4118
1153.5	1.41176	39.4118	85.6078
1153.58	4.86275	55.5686	91.4902
1153.67	9.21569	71.4118	96.1176
1153.75	15.4118	84.4706	99.0196
1153.83	27.1373	90.2353	99.7255

1153.92	45.5686	94.9804	100
1154	62.5882	98.1961	100
1154.08	82.3137	99.8039	100
1154.17	93.451	100	100
1154.25	98.549	100	100
1154.33	99.6863	100	100
1154.42	100	100	100
1154.5	100	100	100

Appendix D

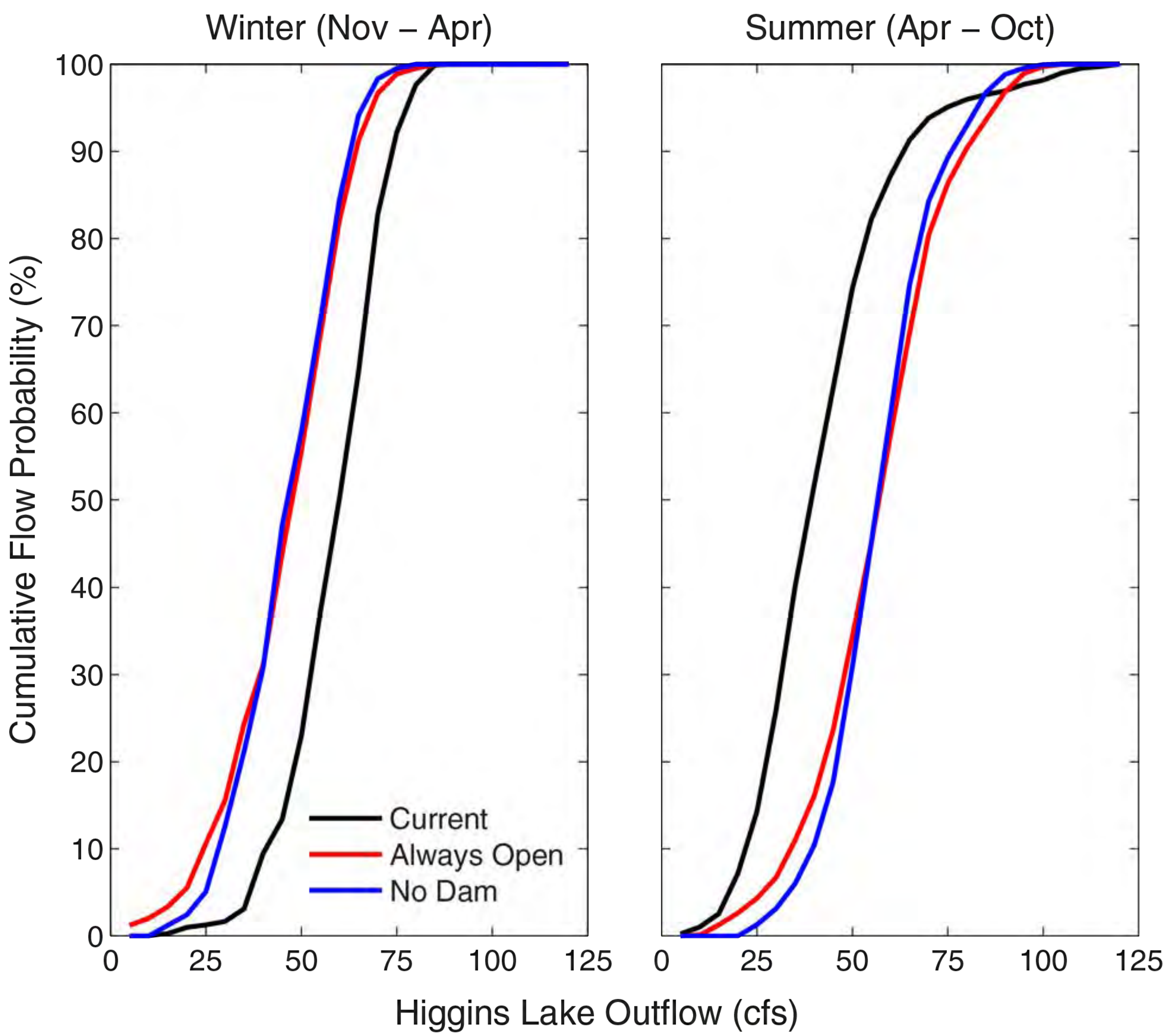
Cumulative Probability of Lake Levels During Winter, Table

Level(ft)	Prob_Curr(%)	Prob_Open(%)	Prob_NoDam(%)
1152.25	0	0	0
1152.33	0	0	0
1152.42	0	0	0.955958
1152.5	0	0	1.33151
1152.58	0	0	2.18505
1152.67	0	0	3.51656
1152.75	0	0	8.02322
1152.83	0	0.238989	12.9737
1152.92	0	1.12666	20.5531
1153	0	2.25333	30.4882
1153.08	0.170707	4.30181	46.8078
1153.17	1.02424	10.2424	57.5964
1153.25	1.70707	16.7293	71.1506

1153.33	5.90645	28.4397	85.0461
1153.42	12.564	44.3837	94.6398
1153.5	26.3913	62.0348	98.4978
1153.58	46.5005	79.72	99.8293
1153.67	63.4005	92.8645	100
1153.75	84.9778	98.0881	100
1153.83	93.24	99.522	100
1153.92	97.3028	100	100
1154	98.8392	100	100
1154.08	99.5903	100	100
1154.17	100	100	100
1154.25	100	100	100

Appendix E

Cumulative Probability of Outflow Figure



Appendix F

Cumulative Probability of Lake Level Figure

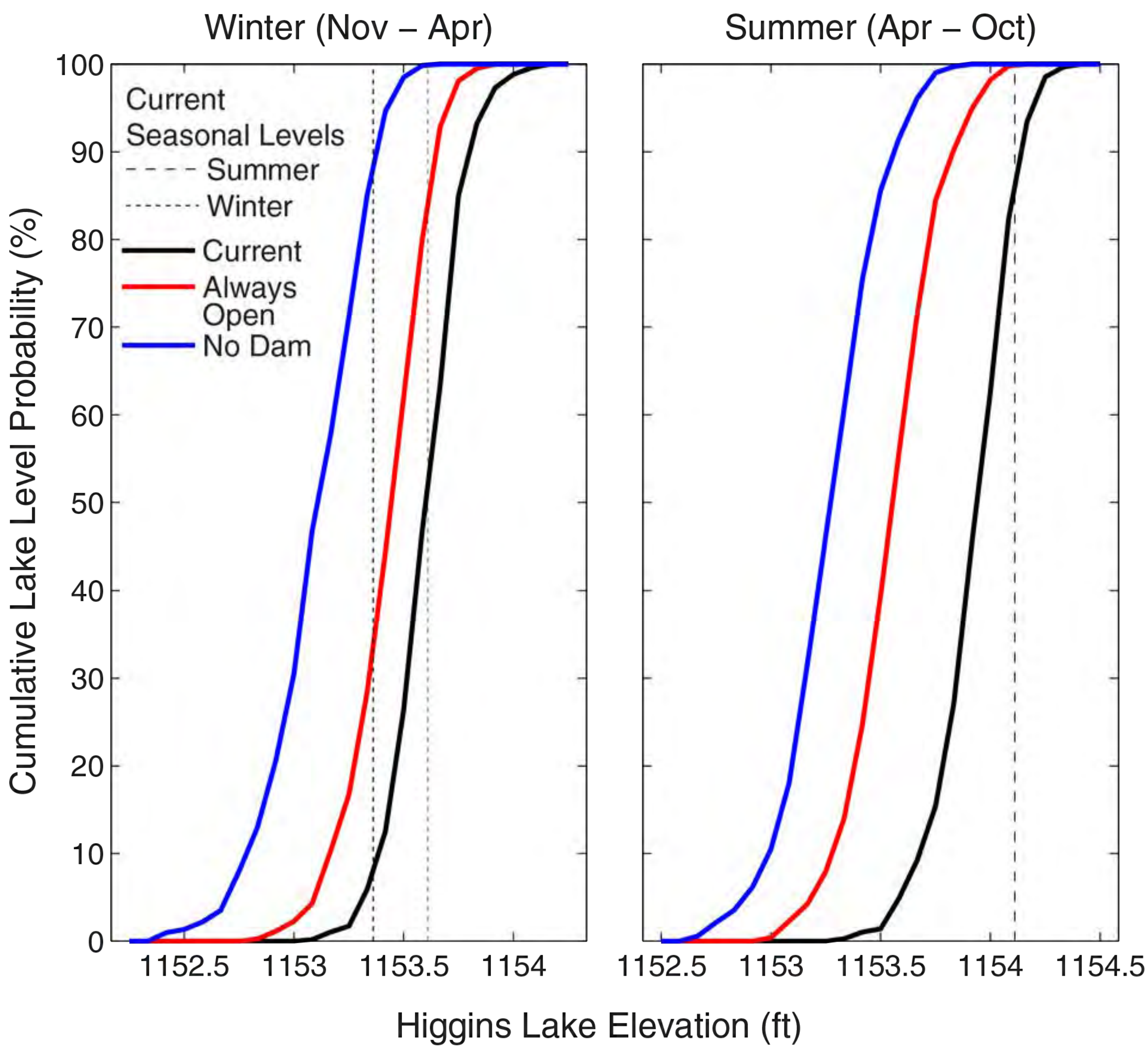


EXHIBIT
5

Final Report to the Muskegon River Watershed Assembly

Name of Study:

Ecohydrologic Evaluation of Removing the Higgins Lake-Level Control Structure.

Prime Contractor: Muskegon River Watershed Assembly

Study Job D.6 Prepare Habitat Models to Examine Fishery-Related Impacts

University of Michigan Subcontract. Michael J Wiley and Andrew J Layman.

A. Problem:

Higgins Lake, in Roscommon County, has a controversial level of shore erosion which has been attributed to high water caused by an old lake-level control structure (dam) at the junction of the lake and the Cut River. The erosion has been severe enough to concern the Higgins Lake Property Owners Association but effects of the erosion on the lake bottom, surrounding vegetation, animal species, and neighboring aquatic habitats have had little study since the dam's construction in 1936. This is despite the fact that the inter-connected Higgins Lake-Cut River-Houghton Lake system comprises the headwaters of the Muskegon River and supports a major inland recreational fishery for Yellow Perch, Smallmouth Bass, Walleye, Lake Trout, Rainbow Trout, Lake Whitefish, Rainbow Smelt, and a number of other species (O'Neal 1997, 2003). The number of angler hours measured during a one year period (2001 – 2002) was 250,962 hours on Higgins Lake and 499,048 hours on Houghton Lake. No data was collected for the Cut but the angler use is relatively high for a smaller river system. The economic value of this combined fishery to the local economy is estimated by MDNR to exceed $6.9 million annually. DNR Fisheries Division stocks Higgins Lake every year with 75,000 trout including lake trout, rainbow trout and brown trout at an annual cost of approximately $75,000. For these reasons, a well-planned and comprehensive assessment of lake level and erosion issues on Higgins Lake must also include an assessment of impacts on fisheries-related habitat and connectivity in the upper Muskegon watershed.

One of the largest inland water bodies in Michigan, Higgins Lake has a surface area of 10,186 acres. It's relatively small watershed includes a number of small tributaries, and it discharges to the Cut River, the headwater of the Muskegon River, which then runs by Marl Lake and joins with Backus Creek before entering Houghton Lake. The Higgins Lake Property Owners Association (HLPOA) contacted DNR Fisheries Division with their concerns regarding the excessive shoreline erosion in 2010. Records and data from the 1939 Fisheries Division survey of the lake indicate reductions have occurred in the amounts of gravel bottom, floating vegetation, and emergent vegetation. In the interim, studies of the dam were done in 1956, 1969, and 1995.

Manipulation of the dam's height to control water levels in Higgins Lake has resulted in large variations in flow to the Cut River, including periods with little to no outflow from Higgins, which MDNR worries will affect downstream fish communities and vegetation, and also those of Marl and Houghton lakes. This is a concern for the fish species that use the Cut River for spawning, including walleye, a recreational sport fish that helps support an important fishery in Houghton Lake. The Cut itself supports an active Smallmouth bass sport fishery, and Smallmouth also constitute an important sport fish in Higgins Lake. Since the control structure limits (but does not completely block) the passage of fish between Higgins Lake and the Cut River, there is also concern that current operations might restrict reproductive success of both species in this connected lake and river system.

B. Background:

The original lake-level control structure at the outlet of Higgins Lake was constructed in 1936, apparently to improve boating and swimming (1952 letter from Higgins Lake Property Owners Association). But the dam fell into disrepair after a period of time because no specific organization managed it. Portions of the existing structure were constructed in 1950 as part of a Roscommon County Improvement Project (Ayers et al. 1995). The legal level of Higgins Lake was set in 1982 at 1154.11 feet above mean sea level for summer, and 1153.61 feet for winter months. In 2009, the legal winter level was temporarily amended (effective through 2013/2014) to be 1153.36 beginning between September 15 and November 1. Roscommon County is responsible for operation, maintenance, and improvement of the dam.

The DNR Fisheries Division has received complaints that the dam has severely restricted flows to the Cut River leading to both lake levels above legal limits and periodic drying of the stream bed. Fisheries Division expressed concerns with improper regulation of the dam in a letter to the Roscommon County Board of Commissioners in 2004.

In 1995, Roscommon County and the Higgins Lake Property Owners Association contracted an engineering firm to evaluate characteristics and capacities of the dam to determine if fluctuations in the lake-level could be minimized. Information from this study was summarized by Ayers et al. (1995), who also indicated earlier lake level control studies had been completed by the Michigan Department Conservation in 1956 and Ayers, Lewis, Norris and May in 1969. Ayers et al. (1995) recommended adding 62 feet of additional spillway to increase the outlet capacity of the structure from 55 cubic feet per second (cfs) to 110 cfs, which would enable lake level maintenance for storms up to a 5-year frequency. The additional flow capacity was added to the structure in 2007. At the request of DNR Fisheries Division, a permanent low flow opening (4.75 feet) in the outlet dam was installed in 2007 to allow to maintain a minimum flow at or near the 95% exceedance flow to the Cut River (approx.. 50 cfs). In 2010, Roscommon County retained an engineering firm, Spicer Group, to inspect the structure and evaluate its hydraulic capacity and water control. Spicer Group (2010) confirmed that the dam has similar outflow capacity (with all gates open) as the Cut River as a result of the additional flow capacity added to the dam in 2007. They found that summer lake levels were lower following installation of the low flow channel and recommended the low flow channel be closed during the summer to help maintain legal lake levels. Evaporation resulted in the greatest loss of water in the system based on simple mass balance estimates.

C. Objectives:

The purpose of this study was to evaluate the likely effects of modifying operations of, or removing the water level control structure between Higgins Lake and the Cut River system. Participating stakeholders in this project included DNR Fisheries Division, DEQ Water Division, the Muskegon River Watershed Assembly (MRWA), the Higgins Lake Property Owners Association, the Higgins Lake Foundation, Huron Pines and researchers from Michigan State University (MSU) and the University of Michigan (UM). Over the period of the study, a series of water management scenarios were developed through conversations with the primary stakeholders, funders, and researchers including representatives of HLPOA, MRWA, MDEQ, and the MSU and UM teams (Table 1). In this section (UM study report) we treat primarily the fishery-related habitat consequences associated with the specified scenarios for both Higgins Lake and the Cut River.

The project directly addresses Management Actions 1, 16, 18 & 21 in the Muskegon River Management Plan (O'Neal 2003). These management actions involve restoring fish passage and natural hydrologic conditions in the system to restore habitat and biological communities.

Table D.6.1. Water level management scenarios examined in this study. All are referenced to the current legally (court) specified summer water level (SLL). The bracketing "extreme" high and low level scenarios were included for calibration and sensitivity analysis purposes and are not actual management possibilities

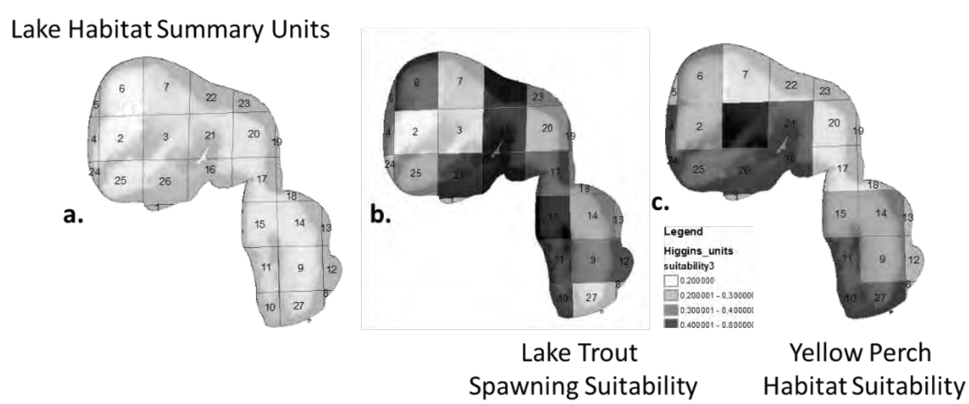
Scenario	Description	WSE (m AMSL)	WSE (ft AMSL)	Change in m	Change in ft
SLL +60	Extreme high (sensitivity test)	353.273	1159.03	1.5	4.92
SLL +1	All gates closed	351.803	1154.21	0.03	0.10
SLL	Summer legal level	351.773	1154.11	0	0.00
SLL -9	Proposed new SLL	351.543	1153.36	-0.23	-0.75
SLL -18	All dam gates open	351.313	1152.60	-0.46	-1.51
SLL -26	Dam removal	351.113	1151.95	-0.66	-2.17
SLL -60	Extreme low (sensitivity test)	350.273	1149.19	-1.5	-4.92

Task D.6.1 Potential impacts on Higgins Lake Fishes & Fishery

D.6.1. METHODS

Overview: To assess the possible impacts of altered water surface elevations (WSE) related to changes in dam management we have focused on modelling habitat changes for (a) a representative set of species of interest to anglers and (b) some typical prey (forage) species. We chose species for our analysis based on the following criteria: (1) one or more published Habitat Suitability Index models (Terrell et al, 1982; Zajak et al. 2015) were available; (2) the suitability models indicated that small changes in depth, or vegetation cover, or substrate distributions (singly or in combination) could significantly affect habitat quality; (3) the species was of interest to Higgins Lake anglers and/or might support the forage base of such species. For those fishes (Table D.6.2)., HSI models were constructed using only model input variables which could be directly related to or modeled from changes in bathymetry These variables included depth, light penetration, extent of littoral and profundal zones, submersed aquatic vegetation cover (SAV), and substrate distribution and availability. All other HSI variables were assumed to be optimal, given that the fishes being modeled are all common in Higgins Lake, and that the focus of the study was to assess impacts related only to potential changes in water surface elevation. To implement the HSI models we needed first to produce WSE sensitive models of basin bathymetry (see MSU final report), substrate, and vegetated cover. Detailed descriptions of the field sampling methods employed, SONAR signal processing, GIS, and statistical methods used to produce these input models can be found in Appendix A (Layman 2015).

For each of the habitat suitability models the lake basin was partitioned into 27 subunits based on intersections of county section lines (figure D.6.1a). HSI values and weighted useable area estimates were computed for each species and management scenario combination in each of these lake subsections and then summed to provide a total habitat quality rating of the lake. Lake habitat subunits were evaluated individually and then summed to represent the entire lake; note individual units can be mapped using GIS to visualize the spatial distribution of available habitat (e.g. figure D.6.1b,c).



Specific Modeling Methods

Predicting Aquatic Vegetation

Important factors effecting the occurrence and distribution of submersed aquatic vegetation (SAV) include light, substrate texture/ stability, wave disturbance, and hydrostatic pressure (Figure D.6.2).

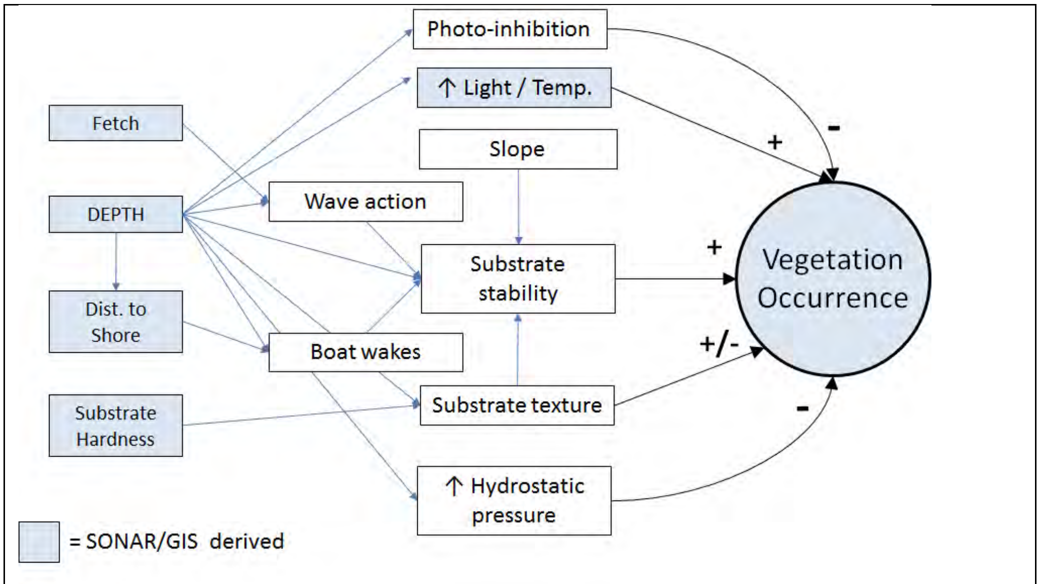


Figure D.6.2. Conceptual model linking factors influencing the occurrence and distribution of aquatic vegetation to key variables measured during this study (in blue).

Since depth affects all four, it necessarily exerts a strong overall control on SAV distribution. During thermal stratification, vertical distributions of temperature and light are correlated in lentic systems; both decreasing with depth. Substrate conditions also influence SAV distributions; substrate stability and penetrability both being important to rooted vascular species. Wave action (energy dissipation per unit depth), substrate texture (grain size) and bottom slope influence substrate stability. When sediments are unstable, vascular plants are more likely to be dislodged and less likely to become established. Sediment texture can also directly influence likelihood of SAV establishment; for example, a cobble bed may be particularly stable and suitable for attached algae but not allow penetration of vascular rooting structures.

Binary logistic regression was used to produce a statistical model relating the distribution of SAV in response to changes to lake-level arising from different management scenarios. Following a similar model developed for bays and estuaries of Lake Superior (Angradi et al. 2013), we explored the following variables as potential predictors: water depth, slope, directionally-weighted fetch, substrate hardness, and percent light remaining at depth, plus all 2-way interactions between predictors using manual step-wise selection. Substrate hardness data was natural log transformed. Models were fit using GLM (Generalized Linear Model) methods in DataDesk 6.3 (Data Description, Inc.). Data inputs required for the SAV modeling included the development of the following data sets.

1. Fetch- Historical weather data were obtained for the nearby Roscommon County station at Houghton Lake (Houghton, MI). One year of daily average wind direction data was sampled at approximately five year intervals from 1963-2013 and the statistical frequency of wind direction was determined along the four cardinal axes. The directionally-weighted fetch was then computed in MATLAB at a 100 m by 100 m grid resolution, where the value at each location was equal to the sum of the distance to shore in each cardinal direction weighted by the frequency of wind direction in the meteorological record. These data were then imported into ArcGIS and an exact inverse-distance weighting interpolator applied to generate a continuous raster cover for the lake surface.

2. Bathymetric slope- A slope raster surface was generated in ArcGIS as the first derivative of the modeled bathymetric surface. To avoid kriging artifacts and produce a more realistic slope map, a 50 m point grid was used to sample the bathymetric surface and these secondary data were used to produce a "smoothed" bathymetric surface from which the slope surface was calculated.

3. Bottom Substrate- To delineate substrate types in Higgins Lake, the depth-corrected signal attenuation of a 200 kHz sonar was interpreted as index of substrate hardness and served as a proxy for sediment texture in the vegetation model. Signal attenuation values were classed as sediment types (i.e., organic depositional, clay, marl, sand, gravel/hardpan/vegetation) based on a 1936 MDNR substrate survey map of Higgins Lake and on visual assessment during our survey. These sonar-derived hardness data were supplemented with a 100 m regular spaced point grid using average interpreted hardness values and visual classification from air photos.

4. Percent light remaining at depth- This was calculated using the equation:

$$\%\,Light\ remaining\ at\ depth = 100 * e^{-0.05 * Z}$$

   where Z is the depth in feet from the newly developed bathymetric map. The light extinction coefficient value (-0.05) was estimated from 20 years of vertical profile monitoring in Higgins Lake by the Higgins Lake Property Owners Association. No significant difference in light penetration was found between the North and South basins.

Habitat Suitability Index Models

Sources, variables used, and life stages modeled varied by species and habitat (Table D.6.2). Input variables were tabulated and summarized by lake habitat unit in Python and ArcGIS, and HSI values calculated in customized spreadsheets. Results are presented as both total Weighted Usable Area (WUA) and Percent Useable Area (PUA). WUA represents habitat quantity in terms of areal equivalents and was calculated as:

$$\text{Total } WUA = \sum_{i} Composite\ HSI\ value * area\ of\ lake\ unit\ i$$

where i = 1 – 27 Higgin's Lake habitat units as mapped (see method overview above). When a habitat unit's value is 1, WUA = Total area of the habitat unit. PUA is the ratio of the composite WUA to total lake area and is a useful metric of overall habitat quality in contrast to quantity. Individual HSI metric values range from 0 to 1 and reflect the relative suitability of the habitat condition for the focal species/life stage (Terrell et al 1982); composite HSI values were computed as the product of individual component values except where the specific HSI models specified otherwise.

Table D.6.2 Literature sources for Habitat Suitability functions used in this study.

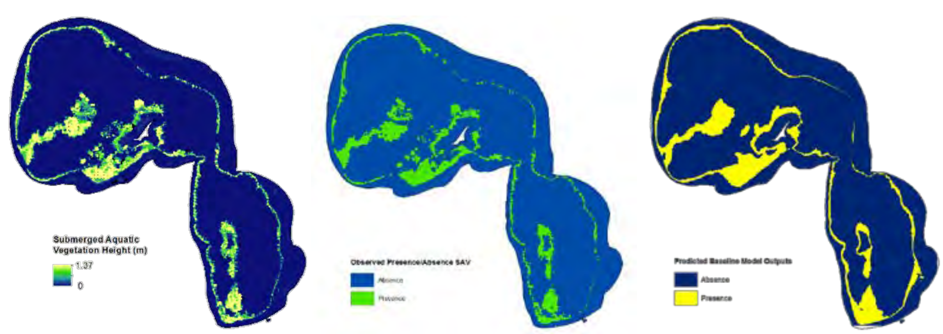
Species	Life stages	Variables used	Literature Source
Higgins Lake WUA models			
Smallmouth Bass	adult, YOY	Substrate, depth, plant cover	Edwards et al. 1983
Northern Pike	general	plant cover, depth	Inskip 1982
Walleye	adult, juvenile, spawning	Substrate, depth, plant cover	McMahon et al. 1984
Yellow Perch	general	Substrate, depth, plant cover	Krieger et al. 1983
Spot tail Shiner	general	Substrate, depth, plant cover	Golder Assoc. 2008
Lake Whitefish	spawning	depth, substrate	Golder Assoc. 2008
White Sucker	spawning	depth, substrate	Tomey et al. 1984
Lake Trout	spawning	substrate	Marcus et al. 1984
Cut River WUA models			
Smallmouth Bass	Adult, Juvenile, Spawning	Substrate[1], depth, velocity	Aadaland and Kuitunen 2010
Walleye	Adult, Juvenile, Fry, Spawning	Substrate[1], depth, velocity	Aadaland and Kuitunen 2010
Black-nose dace	Adult, Juvenile, Spawning	Substrate[1], depth, velocity	Aadaland and Kuitunen 2010
Creek chub	Adult, Juvenile, Spawning	Substrate[1], depth, velocity	Aadaland and Kuitunen 2010
Common shiner	Adult, Juvenile	Substrate[1], depth, velocity	Aadaland and Kuitunen 2010
Brown trout	Adult, Juvenile	Substrate[1], depth, velocity	Aadaland and Kuitunen 2010

D.6.1 RESULTS

Using the new sonar-based bathymetry, substrate, and vegetation data from 2012 field studies we developed a logistic regression model linking bathymetry and substrate conditions to vegetation cover in Higgins Lake (Layman 2015, Appendix A). The best fit logistic model of submersed aquatic vegetation had the following form

$$ln\frac{p}{1-p} = 19.03 - 1.187 * Depth - 0.2086 * \%light + 0.0201 * \%slope - 0.00196 * fetch$$

Where p is the probability that the dependent variable (aquatic vegetation) is present, depth is water depth in meters, %light is percent of surface light intensity,% slope is percent slope of the bathymetric surface, and fetch is directionally weighted mean fetch in meters. A threshold value of 0.3675 was used to classify the linear output of the logistic equation into binary presence/absence predictions. This corresponds to a threshold probability of 0.591. The classification accuracy of the categorical model with respect to the input data was 82.5% and the classification error rate was 17.5% (Fig. D.6.3).



Observed
Modeled

Observed

Fig D.6.3 Observed and Modeled SAV distributions for summer 2012

We then used this model to predict changes in SAV distributions as a function of WSE as projected in each of the water level management scenarios. Changes in predicted vegetation distributions were relatively minor across the various water level scenarios (Table D.6.3, Fig. D.6.4, Appendix A) with whole lake % cover values ranging from 13 to 14%, and acres of vegetation decreasing only slightly at lower water surfaces elevations. In the extreme sensitivity runs, higher water levels (SLL+60 inches) resulted in a more substantial increases of both acreage and % cover in SAV, but in the extreme low scenario (SLL -60 inches) SAV decreased modestly and maintained a % cover near 13%. Overall the response of SAV to WSE had a slightly parabolic shape with higher % covers occurring at both WSE extremes. Within the range of elevations of interest as management targets all changes in vegetation were small; acreage decreased slightly with decreasing depth, but lake-wide % cover remained relatively stable since water surface area was also decreasing (see Table D.6.4).

Table D.6.3 Modeled responses of submerged vegetation cover to varying Water surface elevations.

WSE (ft) AMSL	WSE (m) AMSL	WSE Change (m)	Lake Area (acres)	% Cover SAV	Acres SAV
1154.2	351.80	0.03	10340	13.69	1416
1154.1	351.77	0	10216	13.75	1405
1153.3	351.54	-0.23	10097	13.28	1341
1152.6	351.31	-0.46	9943	13.08	1301
1151.9	351.11	-0.66	9801	13.02	1276
1159.0	353.27	1.5	11856	21.67	2569
1149.2	350.27	-1.5	8731	13.61	1188

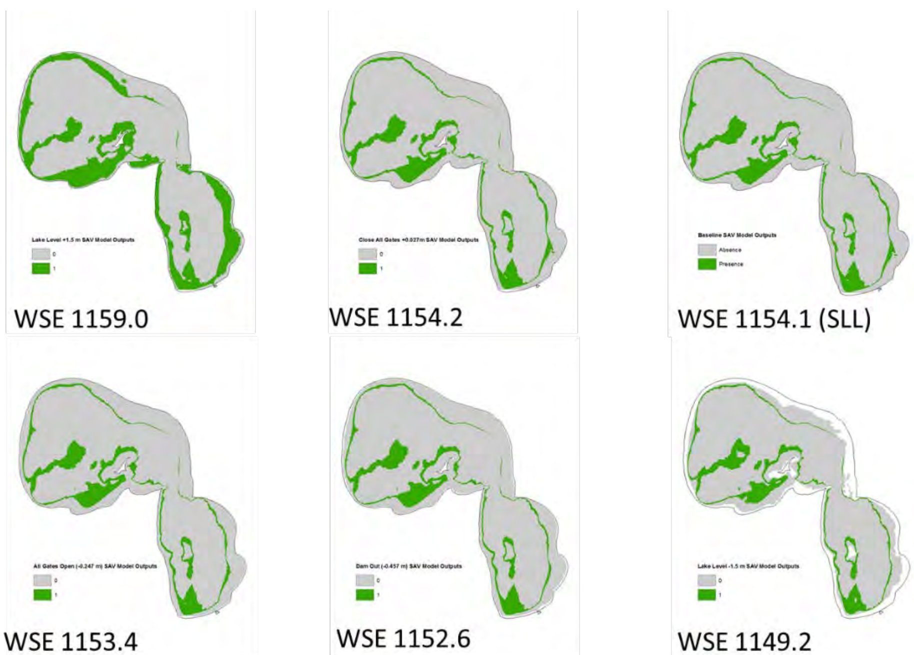


Figure D.6.4 Modeled SAV distributions for various WSE scenarios. SLL indicates current summer legal level.

Table D.6.4. Modeled fish habitat availability in Higgins Lake by WSE scenario

	WSE (ft AMSL)	1151.9	1152.6	1153.4	1154.1	1154.2	1159.0	1149.2
	relative to SLL	SLL -26	SLL -18	SLL -9	SLL	SLL +1	SLL +60	SLL -60
	description:	Channel elv	All boards dwn	Pr. new SLL	Current SLL	All boards up	*sensitivity check*	
	change rel. SLL (ft)	-2.17	-1.51	-0.75	0.00	0.10	4.92	-4.92
	Lake surface (acres)	9,942	10,086	10,167	10,181	10,181	10,202	8,730
Submersed Vegetation	% Littoral vegetated	36.6%	37.3%	38.1%	38.5%	38.4%	36.6%	29.9%
	% of Lake vegetated	13.1%	13.2%	13.2%	13.8%	13.9%	21.7%	13.6%
Smallmouth Bass Adult	WUA (acres)	1,749	1,757	2,052	2,517	2,517	1,749	840
	%change WUA	0%	0%	17%	44%	44%	0%	-52%
	%useable	18%	18%	21%	25%	25%	18%	8%
Smallmouth Bass Spawning	WUA (acres)	248	250	251	281	281	155	106
	%change WUA	0%	1%	1%	13%	13%	-38%	-57%
	%useable	2%	2%	2%	3%	3%	2%	1%
Northern Pike	WUA (acres)	1,473	1,625	1,465	1,623	1,673	2,754	1,070
	%change WUA	0%	10%	-1%	10%	14%	87%	-27%
	%useable	15%	16%	14%	16%	16%	27%	12%
Walleye Adult	WUA (acres)	3,710	3,900	3,942	3,797	3,797	5,988	2,993
	%change WUA	0%	5%	6%	2%	2%	61%	-19%
	%useable	37%	39%	39%	37%	37%	59%	34%
Walleye Juv	WUA (acres)	2,032	2,011	2,020	2,000	2,000	2,704	1,589
	%change WUA	0%	-1%	-1%	-2%	-2%	33%	-21%
	%useable	20%	20%	20%	20%	20%	27%	18%
Walleye Spawning	WUA (acres)	1,040	1,307	1,239	1,125	996	-	-
	%change WUA	0%	26%	19%	8%	-4%	-100%	-100%
	%useable	10%	13%	12%	11%	10%	0%	0%
Yellow Perch	WUA (acres)	3,532	3,583	3,390	3,494	3,513	5,033	3,254
	%change WUA	0%	1%	-4%	-1%	-1%	42%	-8%
	%useable	36%	36%	33%	34%	35%	49%	37%
Spot tail Shiner	WUA (acres)	2,824	2,808	2,838	3,270	3,270	3,465	3,133
	%change WUA	0%	-1%	1%	16%	16%	23%	11%
	%useable	28%	28%	28%	32%	32%	34%	36%
Lake Trout Spawning	acres	236	249	262	284	285	286	177
	%change	0%	6%	11%	21%	21%	21%	-25%
	%useable	2%	2%	3%	3%	3%	3%	2%
Lake Whitefish Spawning	acres	183.36	342.75	405.13	463.69	551.91	588.26	405.13
	%change	-60.46	-26.08	-12.63	0.00	19.03	-36.59	-56.33
	%useable	2%	3%	4%	5%	5%	6%	5%
White Sucker	acres	1,615	1,683	1,730	1,737	1,733	1,674	950
	%change	0%	4%	7%	8%	7%	4%	-41%
	%useable	16%	17%	17%	17%	17%	16%	11%
average response	WUA (acres)	1,695	1,774	1,781	1,872	1,874	2,218	1,320
	%useable	17.0%	17.6%	17.6%	18.4%	18.5%	21.8%	15.0%
	WSE (ft AMSL)	1151.9	1152.6	1153.4	1154.1	1154.2	1159.0	1149.2

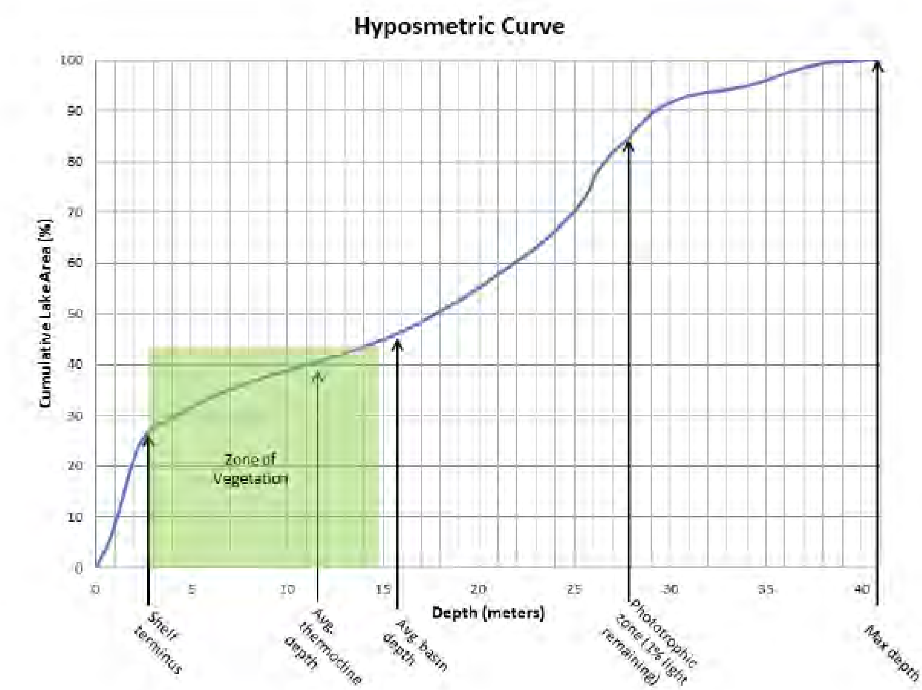
Fish habitat responses to WSE scenarios were similarly muted (Table D.6.4, preceding page). WUA and PUA values for Smallmouth, Northern Pike, and Spottail Shiner declined somewhat with lowered WSEs. On the other hand Yellow Perch and Walleye showed small gains. Walleye spawning habitat and Lake Whitefish spawning habitat were the most sensitive of the WUAs evaluated. Walleye spawning decreased with increasing WSE, while Whitefish spawning area increased rather dramatically. The average (across taxa) habitat response varied from the baseline (1151.9 ft, channel elevation) by 11% at the most, declining with reduced water elevations. Average PUA was even less variable, staying near 19% across all change scenarios (the SLL average value was 18%).

D.6.1. DISCUSSION

The responses of both the vegetation and fish habitat models to more extreme forcing in the sensitivity runs verifies that the models themselves were adequately sensitive to water level change. Nevertheless, the range in WSE elevation change being discussed in terms of management options (and represented in the WSE scenarios we explored) appear to be too small to have large impacts on either the SAV or fish HSI models, and by implication on Higgins Lake fish habitats. This is perhaps not very surprising given the volume and depth of Higgins Lake. With an average depth of slightly more than 52 feet, the scenarios being discussed involve depth changes ranging from < $1/10^{th}$ of 1% of the average, to a maximum of about 4% of the average depth when the lake level is set to the current channel outlet elevation.

Of course the impacts of removing the current dam on fish habitat would depend on the hydraulic details of the physical outlet remaining. Cross-sectional area and roughness would control outlet WSE and so is difficult to predict with precision a dam out water elevation for the lake in advance. The bottom of the outlet channel (1151.9 ft AMSL), was used as a baseline for our comparison in Table D.6.4. It represents the lowest physically conceivable WSE for Higgin Lake given the outlet constraint. However, this is not likely the “natural” pre-dam level, nor the level that would likely follow a dam removal. Based on the lake shore boundary as surveyed in the circa 1840 General Land Office Survey, we estimate that the elevation of the un-regulated outflow to the Cut River at that time was probably near or a bit below 1153 ft. The projected lake boundary for the WSE 1152.6 ft scenario (all boards open) provides a close approximation to the GLO-mapped shoreline and so is our best estimate of both the pre-lake level control condition, and of a reasonable target elevation if the existing dam were to be removed. If realistic WSE regulation options span from 1154.2 ft to 1152.6 ft, then the maximum impact of these differences in terms of fish habitat are even more clearly minimal (maximum average response for PUA and WUA 4-5.5 %).

The reason habitat values are relatively insensitive to the small changes in WSE is related to both the large volume and average depth of Higgins Lake (as noted above), and to the restricted depths at which submersed vegetation flourishes in this lake. Light penetration is good (average seechi depth = 27 ft; MiCorp data) suggesting the trophogenic zone (>1% surface light) extends to 93 ft (28 m). Despite light availability, vegetation coverage in Higgins Lake is low with most of the extensive sandy shelf devoid of vegetation (Fig.D.6.1.E). This is presumably reflects physical substrate instability and low organic content on the extensive shallow sandy shoals. Vegetation is therefore largely restricted to water near the drop-offs and the deeper areas of the western and southern shorelines where wind fetch is reduced (Fig. D.6.5, below)



Large fetch, extensive boat traffic, and possibly some photo-inhibition likely contribute to low SAV coverage on the shoals. In turn, both low SAV coverage and a relative scarcity of gravel and harder substrates suitable for spawning contribute to the relatively low HSI scores for most of the fish taxa examined.

<u>Task D.6.2 Impact of instream flow levels Cut River Fishes & Fishery</u>

D.6.2 METHODS

During the summers of 2013 and 2014 crews from MSU and UM gathered water surface profile, bathymetric, and cross-section data in the Cut River. This report focuses on the river reach centered on the Lansing Rd. Bridge, approximately six river miles downstream from the Higgins Lake Outlet structure. This reach is the most easily accessed and heavily used part of the river by the general public for both fishing and canoe access, although no formal use statistics or creel data are available.

A temporary gauging station was installed by the MSU crew on the upstream side of the bridge in the Spring of 2012, and a flow calibration curve developed. In June 2014 extensive Acoustic Doppler Profiler (ADP), GPS, and traditional land survey methods were used to develop cross-section data for a HEC-RAS hydraulic simulation model of this reach (Fig. D.6.6, Full digital version of the RAS model is available; model geometry file with measured cross-sections in Appendix B). The cross-sections were vertically referenced to the bridge deck (as 1154 amsl; USGS 1963 7.5 min topographic map) and the water surface profile for June 20 2013 (Q = 1.1 cms) used to calibrate the model.

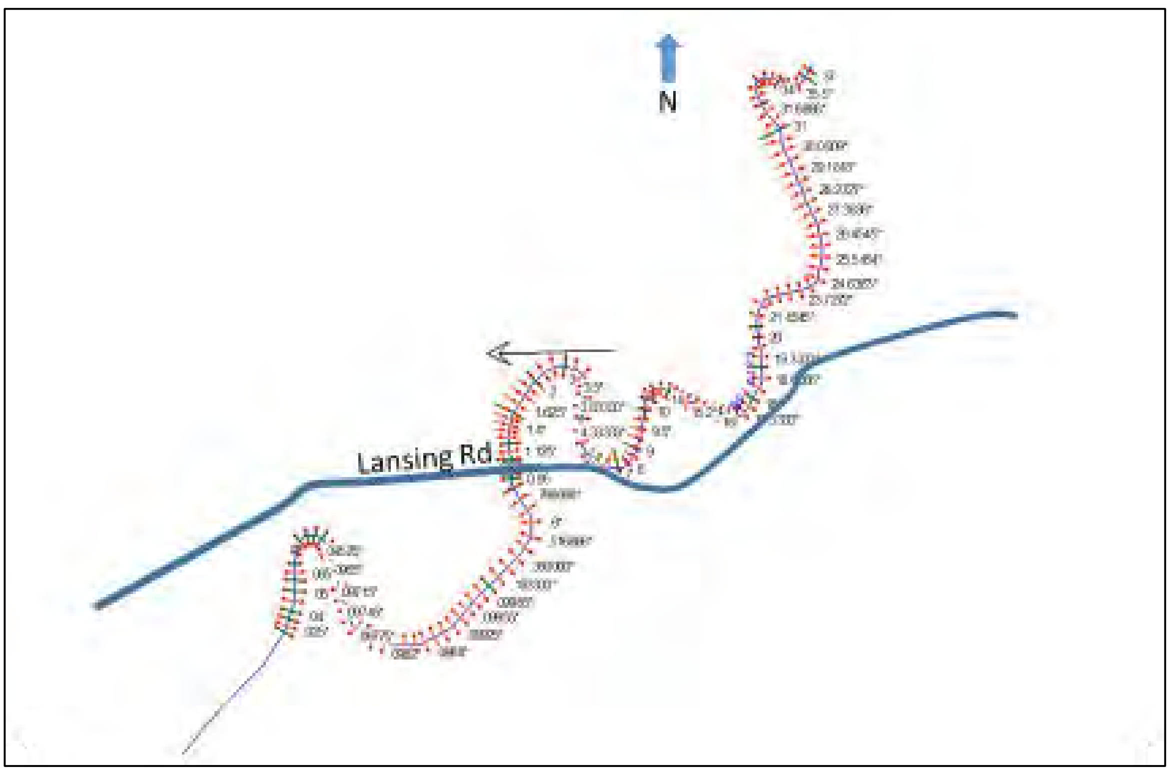


Fig. D.6.6 Channel schematic of HEC-RAS model for the Lansing Rd. Bridge Reach, Cut River.

Standardized HSI functions developed for Minnesota fishes (Aadaland and Kuitunen 2010; Table D.6.1.b, above) were used develop WUA area estimates at representative flows based on HEC-RAS outputs. Simulations were performed as uniform flows and are used here to represent characteristic habitat availabilities at stable flows of 0.25, 0.5, 1.1, 2, 4, and 8 cms (18, 39, 71, 141, and 283 cfs); a range that brackets the flows observed in our gauging study. A complete digital version of the model has been archived with the Muskegon Watershed Assembly.

D.6.2 RESULTS

While there was considerable variation in the amounts of modeled habitat available in the reach with respect to species and life stage, all showed relatively high sensitivity to flow reductions (Fig. D.6.2.7
; Table D.6.5). White Sucker and Smallmouth Bass adult habitat increased more or less in proportionally with flow rate. Reproduction for both of these species was optimal at lower flows, between 100 and 150 cfs. General habitat for adult Walleye was optimal at lower flows (around 75 cfs), however, habitat for spawning adults, fry and juveniles all increased with flow suggesting optimal values > 200 cfs. Most of the other species examined had optimal flows (in terms of hydraulic habitat) in the 100-200 cfs range.

Averaging the flow responses across taxa provides an overview of fish habitat availability for the study reach (Table D.6.6). Plots by life-stage of the combined species data indicate that modeled habitat availability is maximized at flows between 100 and 150 cfs (Fig.D.6.8). In contrast flows < 50 cfs (1.416 cms) show a rapid decline in habitat quality (as assessed by PUA) and availability (as assessed by WUA) for all species and life stages combined, as well as for total wetted channel surface area (Table D.6.6).

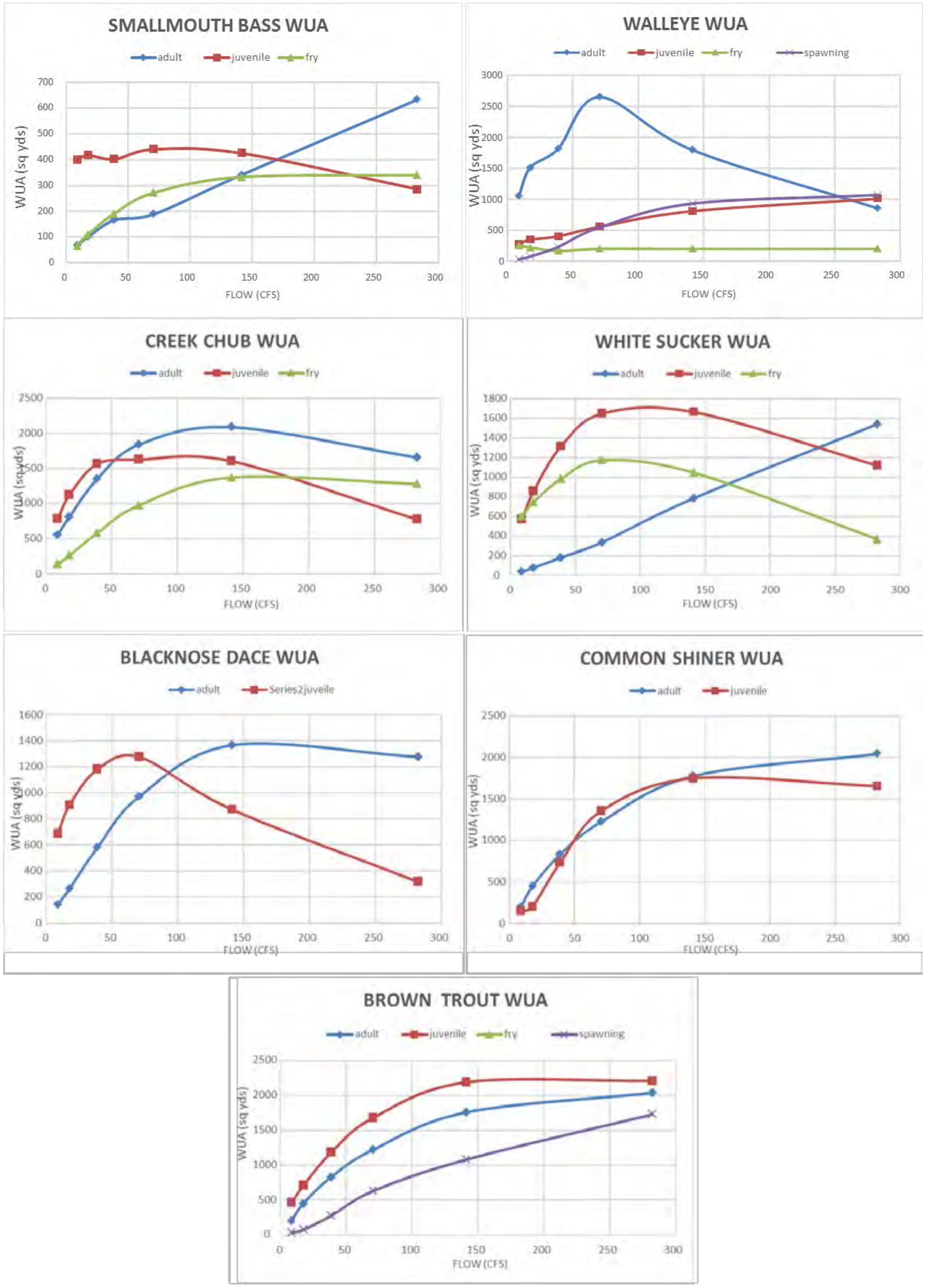


Figure D.6.7 Species-specific WUA response curves

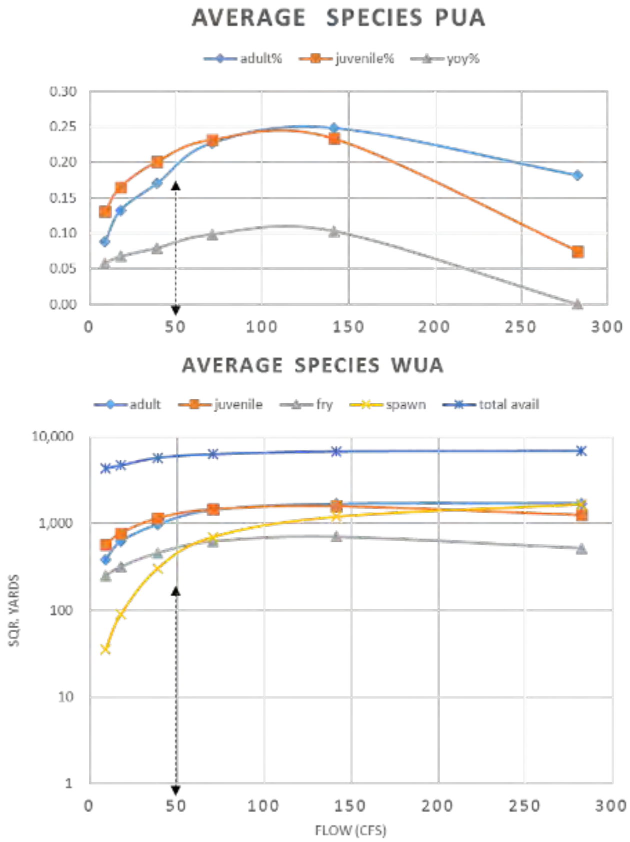


Figure D.6.8. Averaged habitat response curves. Vertical line indicates 50 cfs minimum release target suggested in this report.

Table D.6.5 Lansing Rd Bridge, Cut River WUA and PUA by species

Taxa	cms	cfs	adult	juvenile	fry	spawn	adult%	juvenile%
Blacknose dace	8	283	1277	318			22%	5%
	4	141	1367	872			24%	15%
	2	71	972	1276			18%	24%
	1.1	39	580	1181			12%	25%
	0.5	18	264	907			7%	23%
	0.25	9	141	686			4%	19%
Brown Trout	8	283	2041	2215		1732	35%	38%
	4	141	1761	2195		1083	31%	39%
	2	71	1221	1684		633	23%	32%
	1.1	39	829	1187		281	17%	25%
	0.5	18	445	708		77	11%	18%
	0.25	9	201	463		30	6%	13%
Common Shiner	8	283	2044	1653	3		35%	29%
	4	141	1778	1747	0		31%	31%
	2	71	1228	1355	0		23%	26%
	1.1	39	832	729	0		17%	15%
	0.5	18	448	203	0		11%	5%
	0.25	9	201	149	0		6%	4%
Creek chub	8	283	1655	776	1277		29%	13%
	4	141	2088	1604	1367		37%	28%
	2	71	1840	1628	972		35%	31%
	1.1	39	1351	1567	580		28%	33%
	0.5	18	812	1126	264		21%	29%
	0.25	9	556	788	141		15%	22%
Smallmouth Bass	8	283	634	286	340		11%	5%
	4	141	342	426	333		6%	7%
	2	71	189	441	271		4%	8%
	1.1	39	166	403	191		3%	8%
	0.5	18	100	418	109		3%	11%
	0.25	9	67	400	66		2%	11%
Walleye	8	283	858	1007	195	1062	15%	17%
	4	141	1795	805	195	923	32%	14%
	2	71	2642	552	196	542	50%	10%
	1.1	39	1810	398	162	227	38%	8%
	0.5	18	1511	343	219	73	38%	9%
	0.25	9	1045	272	248	28	29%	7%
White sucker	8	283	1537	1119	364		27%	19%
	4	141	782	1665	1044		14%	29%
	2	71	335	1649	1171		6%	31%
	1.1	39	178	1315	981		4%	27%
	0.5	18	74	856	740		2%	22%
	0.25	9	36	569	598		1%	16%

Table D.6.6 WUA for combined (averaged) taxa; (n=7)

Averaged species scores

WUA (sq yards)

cfs	adult	juvenile	fry	spawn	total avail
283	1,717	1,260	521	1,671	6,927
141	1,694	1,591	703	1,200	6,813
71	1,440	1,467	624	702	6,330
39	982	1,158	458	304	5,760
18	625	779	319	90	4,711
9	384	569	252	35	4,345

B.6.2 DISCUSSION

While the fish habitat WUA analysis in Higgins Lake suggested minimal sensitivity to changes in WSE, the WUA analysis for the Cut indicates that fish habitat has a strong dependence on instream flow rate. Discharge rates in the Cut River are controlled largely by the outflow at Higgins Lake (see Fig.D.6.9 below). Based on same day measurements, there is significant hysteresis in the relationship indicating hydrologic storage in the Cut above the Lansing Bridge. This is likely to include both ground water inputs known to occur in that reach and possibly outputs from Marl Lake and associated wetlands (Carlson 2006, Baker et al. 2006, MSU report). At higher flows there is also evidence of significant off-channel storage in marl Lake and/or bank storage which can buffer the Cut River from higher discharge rates at the outlet. A more continuous analysis of the two gauging station time-series should clarify the mechanisms involved. The result of these storage effects is that during periods of flow transition the relationship between discharge at the dam and flow at the bridge can be quite variable. However, as the plot indicates, on average the relationship is quite strong and is very close to 1:1. This suggests that for the purposes of instream flow management the target discharge rate at Higgin's Lake should be set to desired rates at the Lansing Rd. bridge.

Habitat response curves generated from the Hec-RAS model suggest flows below 50 cfs are severely constraining in terms of relevant fish habitat. This is then a reasonable estimate for a minimum desirable flow. Flows in the range of 100-150 cfs provide optimal habitat benefits based on these analyses. To the extent that Smallmouth and Walleye constitute species of particular interest in this analysis, it is worthwhile to note that significant spawning habitat is available in the Cut for both species. Furthermore, availability of reproductive habitat is strongly tied to flow rate with optimal flows (in this case during the spawning period) above 150 cfs.

Actual flow rates in the modeled reach are controlled by a combination of the discharge from Higgins and storage effects between the dam and the bridge (including interactions with Marl Lake). Nevertheless discharge at the dam outlet appears to be the primary controlling factor, and flow there is constrained by both the configuration of the dam itself and the water surface elevation of Higgins Lake (Fig.D.6.10). There is no evidence that discharge into the cut is constrained by the stream's own channel shape.

Because of these dependencies the lake level required to ensure adequate flow in the Cut also varies with dam configuration as illustrated below. When all gates are open a given lake elevation generates a higher flow to the cut than the same elevation generates when gates are closed or partially opened. The different dam configurations possible lead to distinct lake stage- dam discharge relationships at the outlet. Overlaying information from WUA analysis here it is clear that at lake levels below 1153.6 ft only the all gates open configuration is capable of generating sufficient discharge rates to avoid threatening habitat conditions downstream. Furthermore, with all gates closed, there is no commonly lake level that can deliver adequate, let alone optimal, flow downstream. Mixed gate configurations can provide optimal flows at higher lake levels (>1153.8 ft) and provide adequate flows down to about 1153.6 ft.

Fig. D.6.9. Observed relationship between flow below dam outlet and flow at Lansing Rd.Bridge

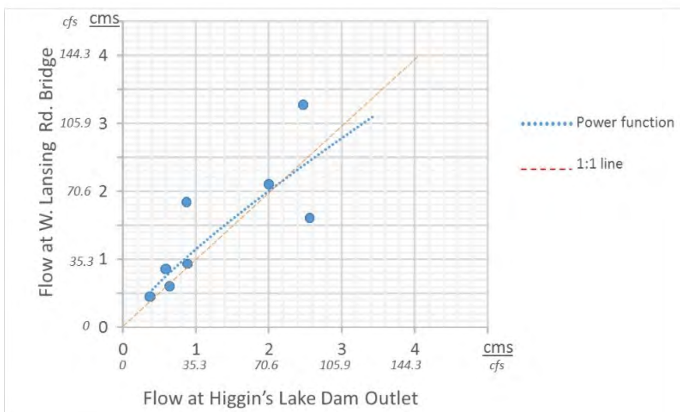
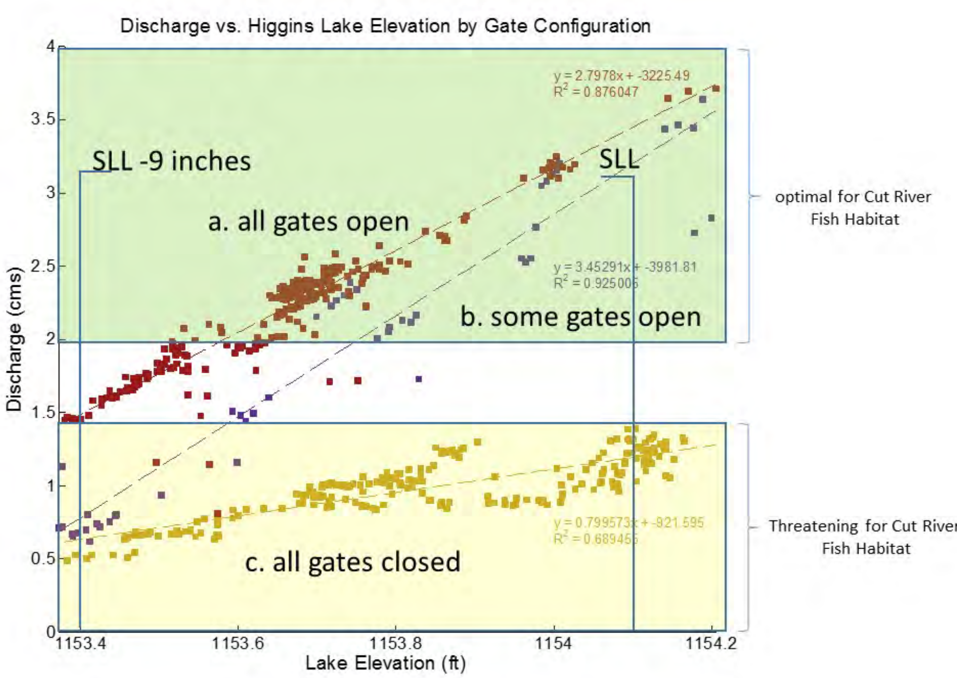


Fig. D.6.10. Relationships between Higgins Lake water surface elevation, dam configuration, dam discharge rate and instream fish habitat at Lansing Rd. bridge reach of the Cut River.



Caveats

It is important to note that WUA and PUA are not direct predictors of either fish population size or fishing quality. The models (both hydraulic and biological) used here attempt only to represent hydraulic and hydraulically linked riverine habitat characteristics (i.e. depth, velocity and substrate) and their relation to flow rate. These models do not reflect constraints of temperature, water quality, fishing pressure, bank management or any other factors which commonly influence local fish population size. Likewise, the analysis uses steady flow assumptions (flow rate is not changing over time or space within the study reach) and so cannot represent variations in habitat associated with flow variation or cumulative effects of flow frequency distributions. The analysis is rigorous, but is only indicative and not predictive in a practical sense. The same is true of the of the HSI-based analyses reported under task D.6.1.

The underlying HSI curves used in both the lake and river analyses represent reasonable summaries of the known habitat preferences and constraints for the species and life stages represented. However, none of the HSI functions we used here were developed locally, nor can be assumed to infallibly represent the habitat requirements of the local populations. They are simply rational summaries of the published literature.

Job D.6 SUMMARY & CONCLUSIONS

In the context of ongoing discussions of water level management in Higgins Lake, the impacts of changing water surface elevations on fish and the regions valuable fishery have been largely overlooked. This study provides MDNR with the first quantitative analysis of the relationships between managed lake elevation and fish habitat features, both in Higgins Lake proper and in the downstream Cut River channel. Based on responses of habitat suitability models to changes in water level and discharge to the Cut River, we draw the following conclusions:

1. The range in the water level targets currently being discussed for Higgins Lake are small enough that none of the scenario levels, including dam removal, are likely to substantially change habitat conditions for the lake fishery.
2. In contrast the Cut River appears to be quite susceptible to low flow disturbance and discharge in the Cut is quite sensitive to variations in both outlet configuration and Higgins Lake water surface elevation.
3. Based on the RAS modeling for the study reach and subsequent WUA analysis, a minimum 50 cfs seems a reasonable target flow rate to protect downstream fishery values.
4. Flows of 100-150 cfs are likely necessary to provide optimal habitat for key species.

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APPENDIX A: LAYMAN THESIS [PDF 67 PP ATACHMENT]
APPENDIX B: HEC RAS GEOMETRY FILE [PDF 22 PP ATACHMENT]

STATE OF MICHIGAN

ROSCOMMON COUNTY CIRCUIT COURT

IN THE MATTER OF: THE WATER LEVELS OF HOUGHTON LAKE, HIGGINS LAKE, AND LAKE ST. HELEN	Case N°· 81-3003-CF

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PROOF OF SERVICE

On the date below, I sent by FedEx Overnight Delivery and email a copy of:

1. Verified Motion to Intervene by Anne and Richard Meeks, Elizabeth Wade, Don Correll, Rhilip Will, Julie and Gary Smith, and Stan Galehouse;
2. Response in Opposition to Relief Requested in Motion to Show Cause by Anne and Richard Meeks, Elizabeth Wade, Don Correll, Philip Will, Julie and Gary Smith and Stan Galehouse, Exhbits 1-5; and
3. Proof of Service.

to the counsel of record of all parties to this cause, at their business address(es) as set forth in the caption and/or disclosed by the pleadings filed in this matter.

The statements above are true to the best of my knowledge, information and belief.

OLSON, BZDOK & HOWARD, P.C.

Date: June 10, 2019

By: Karla Gerds

Karla Gerds, Legal Assistant