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

<u>Study Job D.6 Prepare Habitat Models to Examine Fishery-Related Impacts</u>

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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 lake-level control 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

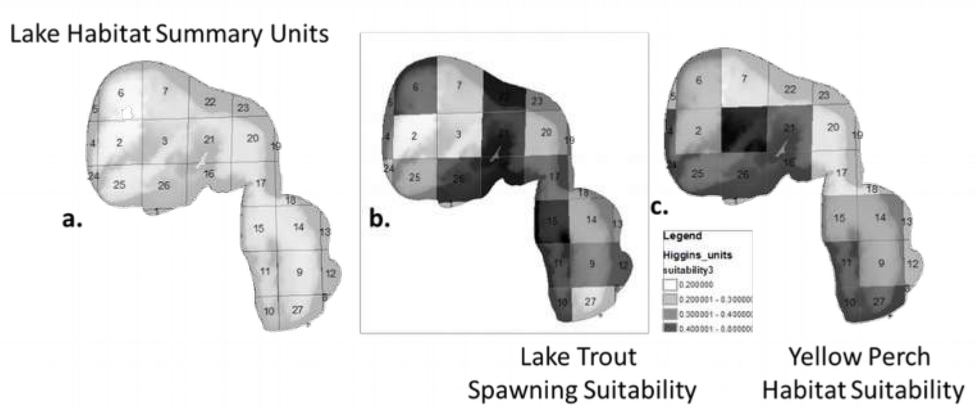
Scenario	Description	WSE (m AMSL)	WSE (ft AMSL)	Change in m	Change in ft
SLL +60	Extreme high (sensitivity test)	353.273	1159.03	1.5	4.92
SLL +1	All gates closed	351.803	1154.21	0.03	0.10
SLL	Summer legal level	351.773	1154.11	0	0.00
SLL -9	Proposed new SLL	351.543	1153.36	-0.23	-0.75
SLL -18	All dam 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).

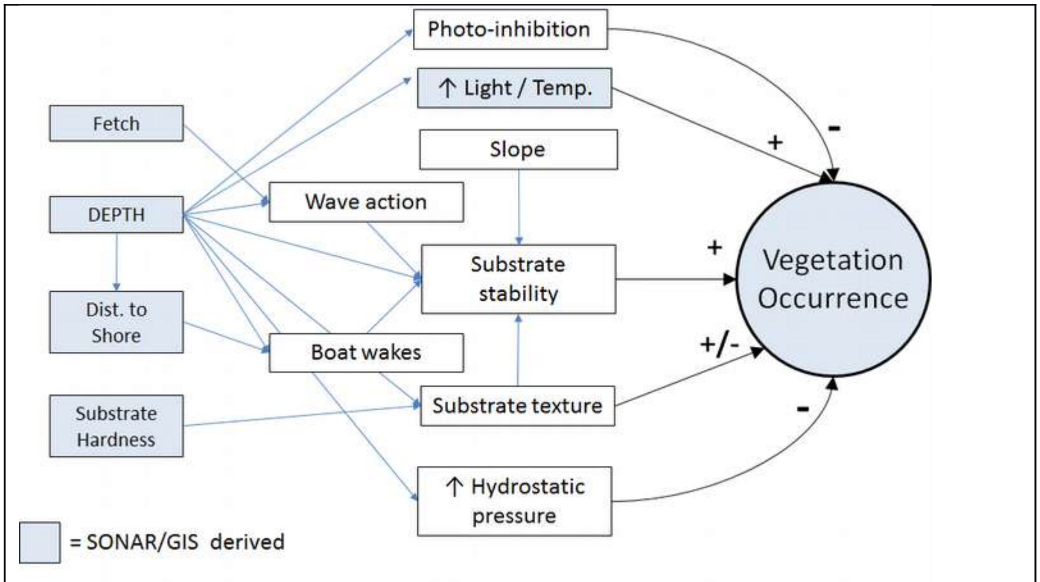


Figure D.6.2. Conceptual model linking factors influencing the occurrence and distribution of aquatic vegetation to key variables measured during this study (in blue).

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 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:

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:

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

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.

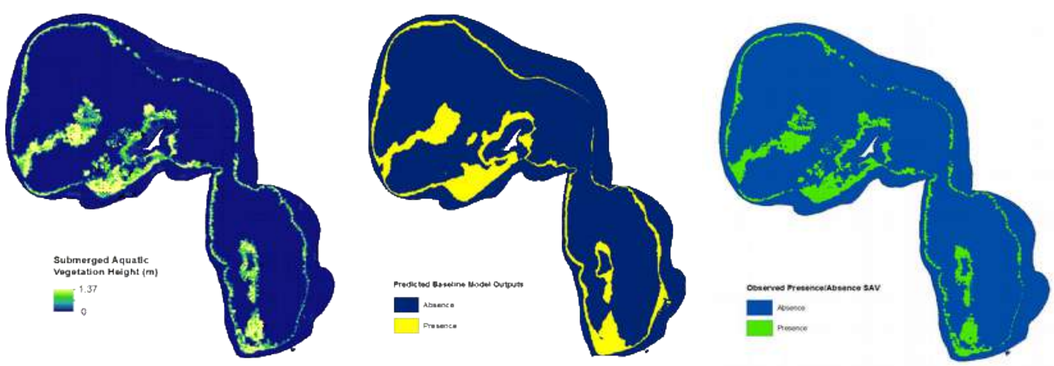
Species	Life stages	Variables used	Literature Source
Higgins Lake WUA models			
Smallmouth Bass	adult, YOY	Substrate, depth, plant cover	Edwards et al. 1983
Northern Pike	general	plant cover, depth	Inskip 1982
Walleye	adult, juvenile, spawning	Substrate, depth, plant cover	McMahon et al. 1984
Yellow 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).



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) with whole lake % cover values ranging from 13 to 14%, and acres of vegetation increasing only slightly at lower water surfaces elevations. In the 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
	353.27	1.5	11856	21.67	2569
1159.0	350.27	-1.5	8731	13.61	1188

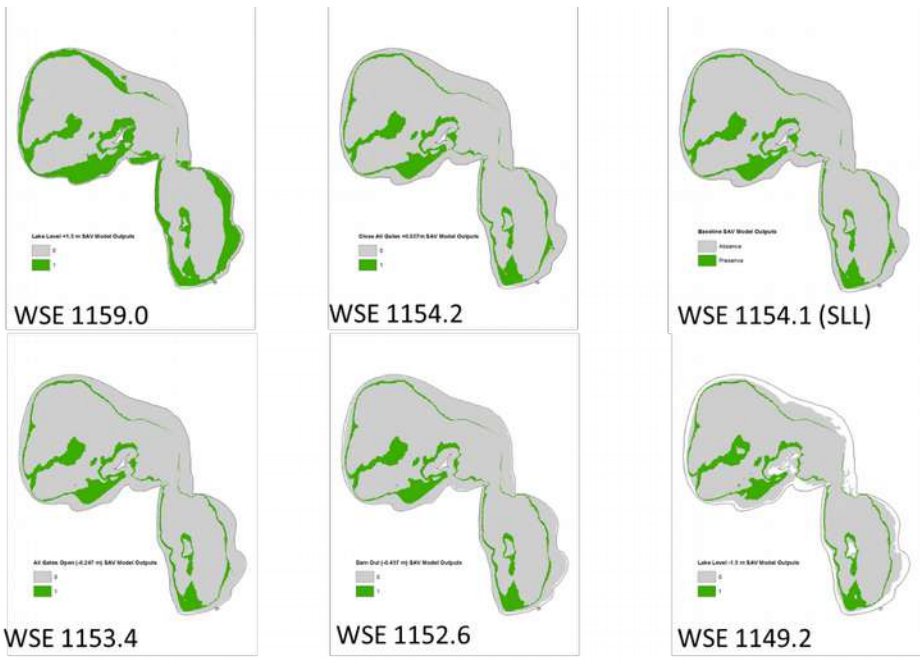


Figure D.6.4 Modeled SAV distributions for various WSE scenarios. SLL indicates current summer legal level.

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:	Outlet elevation	All boards down	adjusted 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%	25.2%	13.6%
Smallmouth Bass Adult	WUA (acres)	1,749	1,757	2,052	2,517	2,517	1,749	840
	%useable	17.6%	17.7%	20.6%	25.3%	25.3%	17.6%	8.4%
Smallmouth Bass Spawning	WUA (acres)	248	250	251	281	281	155	106
	%useable	2.5%	2.5%	2.5%	2.8%	2.8%	1.5%	1.2%
Northern Pike	WUA (acres)	1,473	1,625	1,465	1,623	1,673	2,754	1,070
	%useable	14.8%	16.1%	14.4%	15.9%	16.4%	27.0%	12.3%
Walleye Adult	WUA (acres)	3,710	3,900	3,942	3,797	3,797	5,988	2,993
	%useable	37.3%	38.7%	38.8%	37.3%	37.3%	58.7%	34.3%
Walleye Juv	WUA (acres)	2,032	2,011	2,020	2,000	2,000	2,704	1,589
	%useable	20.4%	19.9%	19.9%	19.6%	19.6%	26.5%	18.2%
Walleye Spawning	WUA (acres)	1,040	1,307	1,239	1,125	996	-	-
	%useable	10.5%	13.0%	12.2%	11.0%	9.8%	0.0%	0.0%
Yellow Perch	WUA (acres)	3,532	3,583	3,390	3,494	3,513	5,033	3,254
	%useable	35.5%	35.5%	33.3%	34.3%	34.5%	49.3%	37.3%
Spot tail Shiner	WUA (acres)	2,824	2,808	2,838	3,270	3,270	3,465	3,133
	%useable	28.4%	27.8%	27.9%	32.1%	32.1%	34.0%	35.9%
Lake Trout Spawning	acres	236	249	262	284	285	286	177
	%useable	2.4%	2.5%	2.6%	2.8%	2.8%	2.8%	2.0%
Lake Whitefish Spawning	acres	183	343	405	464	552	588	405
	%useable	1.8%	3.4%	4.0%	4.6%	5.4%	5.8%	4.6%
White Sucker	acres	1,615	1,683	1,730	1,737	1,733	1,674	950
	%useable	16.2%	16.7%	17.0%	17.1%	17.0%	16.4%	10.9%
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

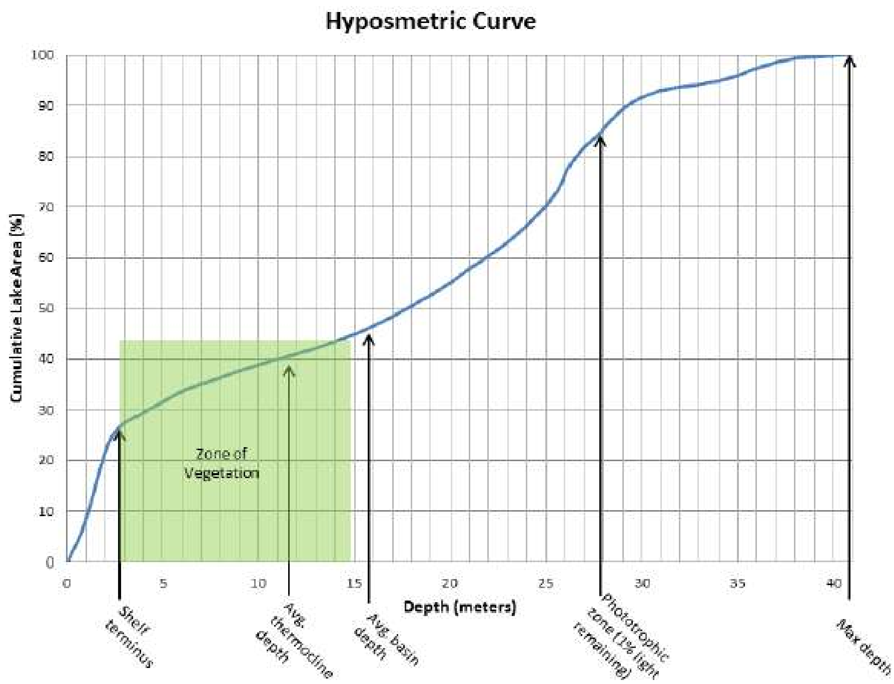
Fish habitat responses to WSE scenarios were similarly muted (Table D.6.4, preceding page). WUA and PUA values for Smallmouth, Northern Pike, and Spottail Shiner declined somewhat with lowered WSEs. On the other hand Yellow Perch and Walleye showed small gains. Walleye spawning habitat and Lake Whitefish 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)



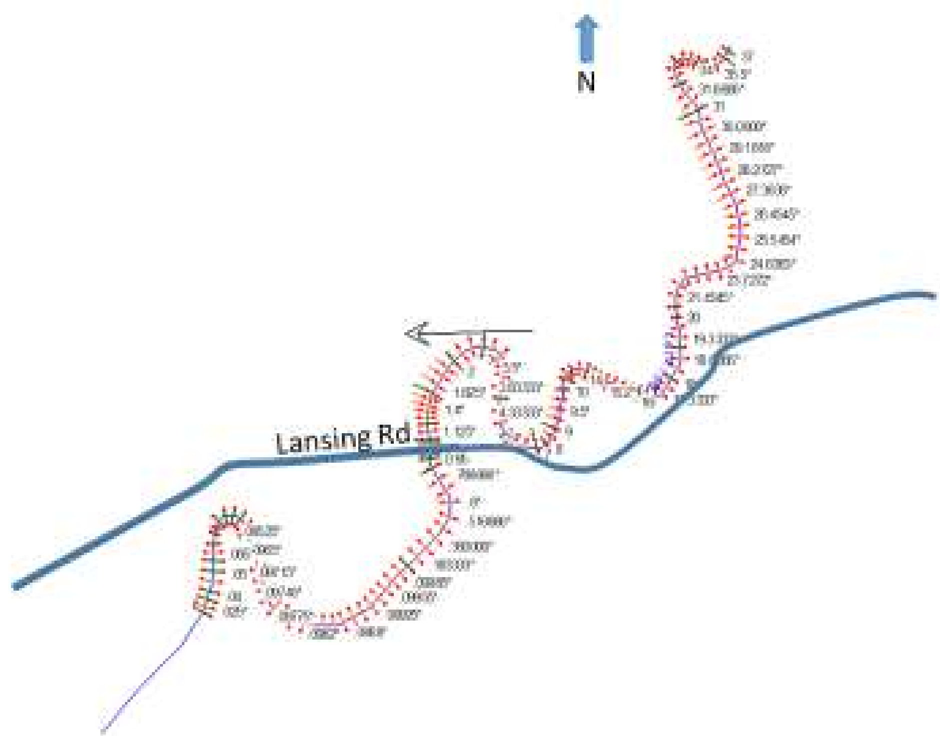
Large fetch, extensive boat traffic, and possibly some photo-inhibition likely contribute to low SAV coverage on the shoals. In turn, both low SAV coverage and a relative scarcity of gravel and harder substrates suitable for spawning contribute to the relatively low HSI scores for most of the fish taxa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

Task D.6.2 Impact of instream flow levels Cut River Fishes & Fishery

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.



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).

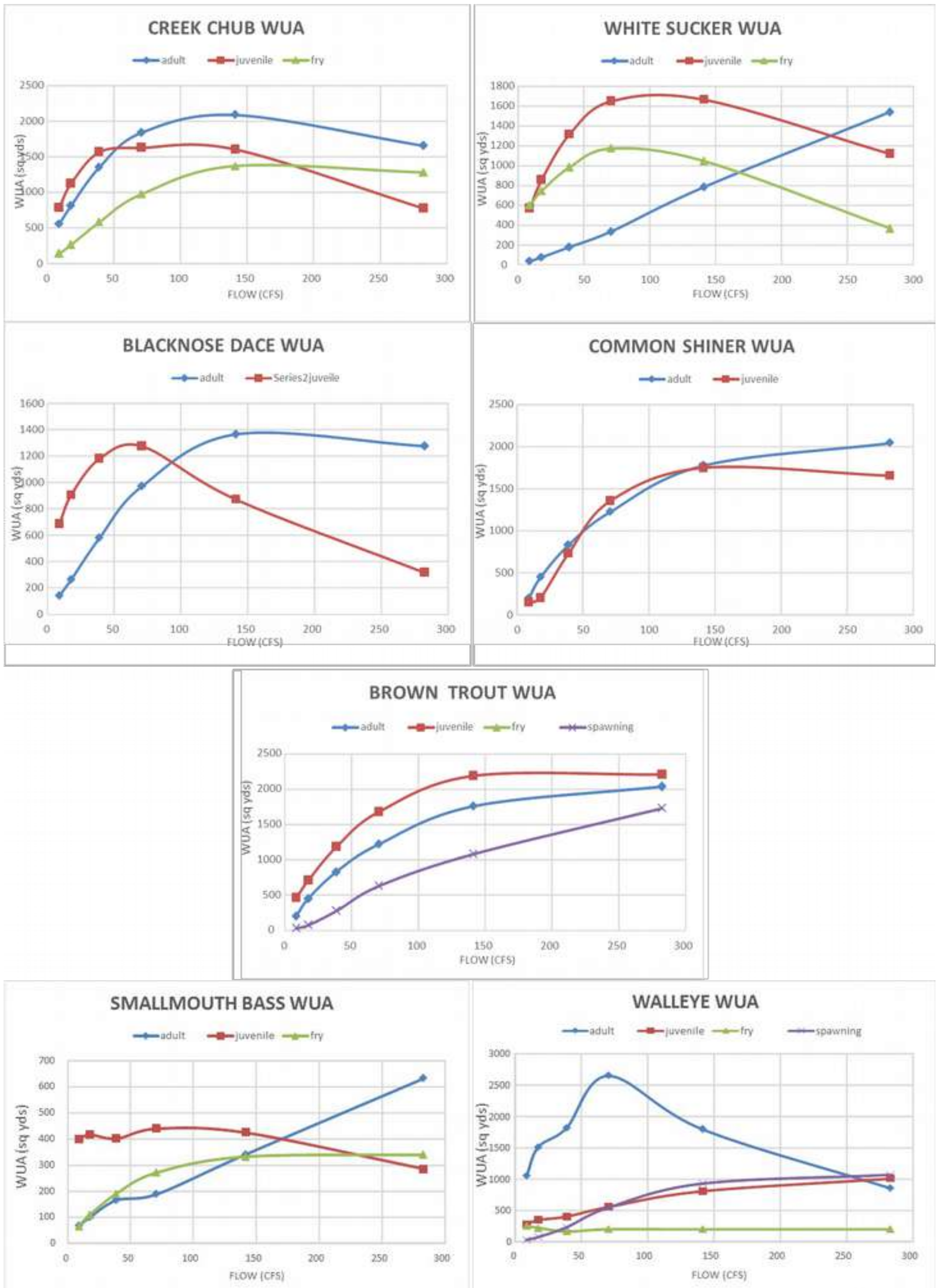


Figure D.6.7 Species-specific WUA response curves

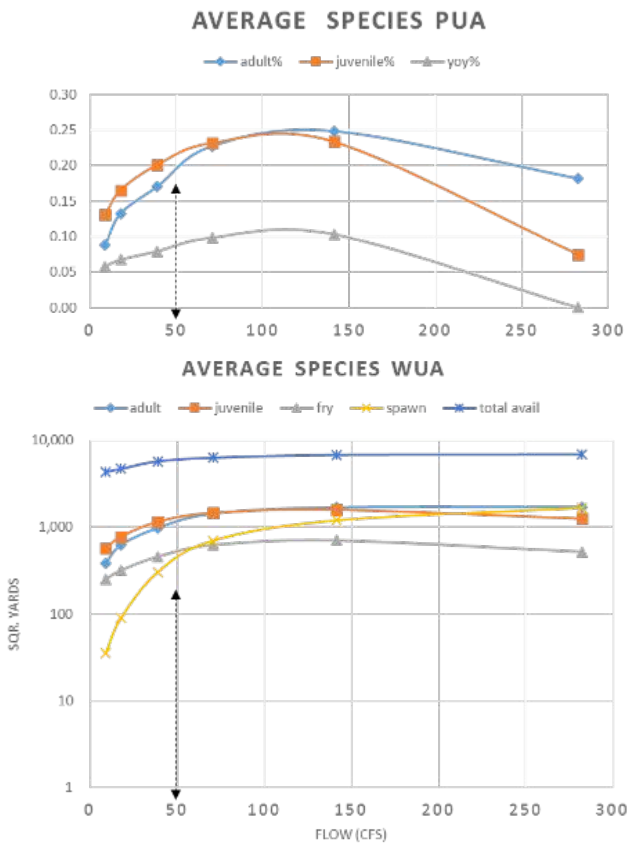


Figure D.6.8. Averaged habitat response curves. Vertical line indicates 50 cfs minimum release target suggested in this report.

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

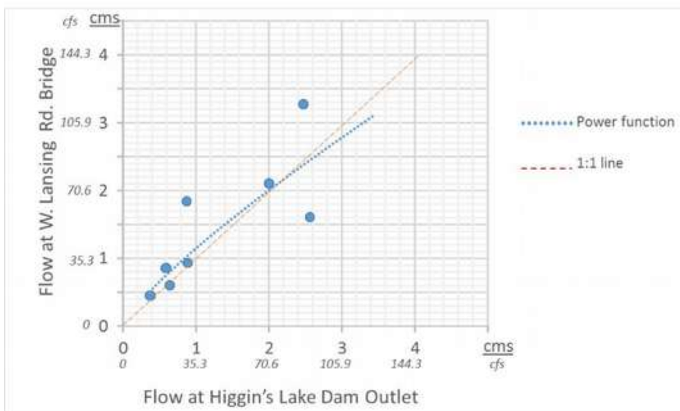
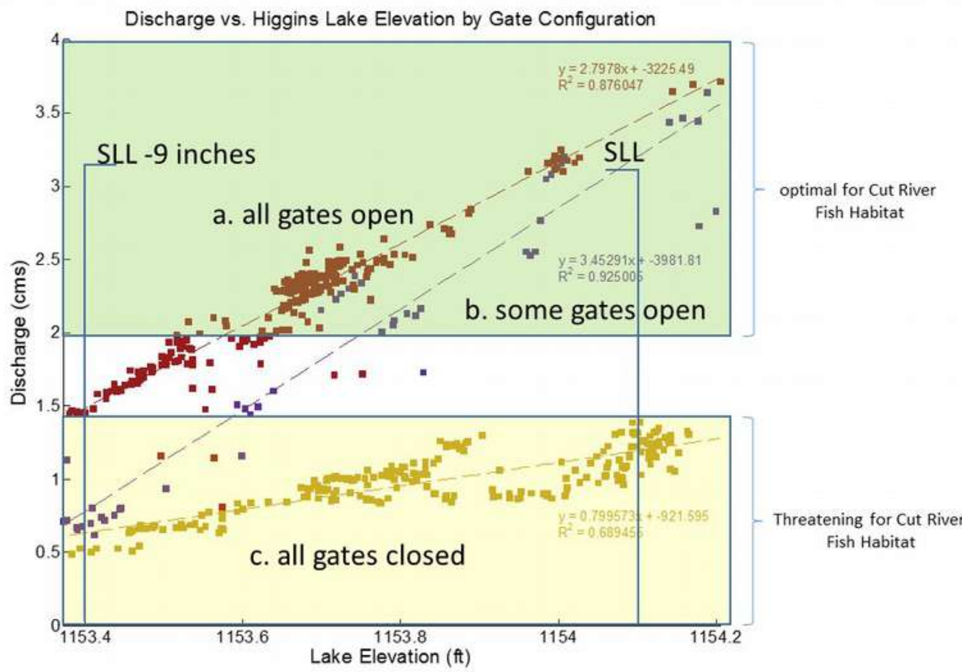


Fig. D.6.10. Relationships between Higgins Lake water surface elevation, dam configuration, dam discharge rate and instream fish habitat at Lansing Rd. bridge reach of the Cut River.



Discharge vs. Higgins Lake Elevation by Gate Configuration
y = 2.7978x + -3225.49
R² = 0.876047
SLL -9 inches
SLL
a. all gates open
y = 3.45291x + -3981.81
R² = 0.925005
b. some gates open
y = 0.799573x + -921.595
R² = 0.689455
c. all gates closed
Discharge (cms)
Lake Elevation (ft)
optimal for Cut River Fish Habitat
Threatening for Cut River Fish Habitat

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]