CE-QUAL-W2 Temperature and Fish Habitat Model of Chester Morse Lake

Model Scenario Report

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Department of Civil and Environmental Engineering

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by

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Introduction

A hydrodynamic and temperature model of Chester Morse Lake and the Cedar River was developed by Wells and Wells (2011) for the period between 1/1/2005 and 12/31/2008. This model was developed with the support of Seattle Public Utilities to provide a tool that would enable operators to determine how climate change and various management scenarios affecting Chester Morse Lake could impact bull trout habitat. The model is 2-dimensional (longitudinal and vertical) and is based on the CE-QUAL-W2 Version 3.7 model (Cole and Wells, 2012). This report will focus on the various model scenarios that were explored using the final calibrated CE-QUAL-W2 model.

Model Scenarios

The model scenarios that were run for Chester Morse Lake were divided into three main categories: climate change, water management, and natural condition scenarios. The first category explores how changes in air temperature, water inflow temperature, flow volumes, and flow timing impact reservoir temperatures and fish habitat. The second category proposes two possible management changes: 1) Increased drawdown from main lake during summer months by pumping water from the main lake to the Masonry Pool when water levels drop below elevation of the flashboard dam, and 2) Increased storage potential of main lake by increasing the elevation of the flashboard dam (gates 1 and 2) by 2 meters, a sketch of which is shown in Figure 1. These two management scenarios are each run separately and in combination. The final category, the natural condition, runs the model with the same input data as for the calibration period but restores the natural lake conditions prior to construction of the Masonry or flashboard dams. This scenario reduced the total segments in the model to 53 from 66 in the original version due to removal of the masonry pool and assumed that the sill elevation of the main lake was at 466 m. Table 1 provides a summary of all the model scenarios.

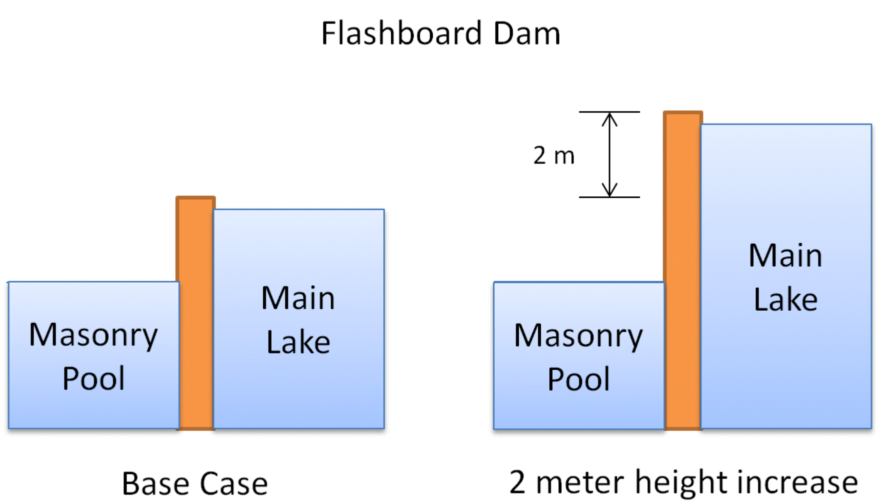

Figure 1. Sketch of 2 meter flashboard height increase

Table 1. Model Scenario Summary

Scenario	Historical MP Water Levels	Inflow temp +2^{o}C	Air temp +2^{o}C	Inflow rate - 10%	Inflow shift earlier 2 weeks	Pump to MP when main pool drops below FB dam (2 m^3/s)	Increase elevation of flashboard dam +2 m	Removal of Masonry Pool – natural lake elevation of 466 meters
Base Case	X							
1-1	X	X						
1-2	X		X					
1-3	X			X				
1-4	X				X			
1-5	X	X	X	X	X			
1-6	X	X	X	X				
1-7	X	X	X		X			
1-8	X	X	X					
2-1	X					X		
2-2	X						X	
2-3	X					X	X	
Natural Conditions								X

Figure 2 shows an example of the 2°C upward temperature shift applied to all inflows to Chester Morse Lake for scenarios 1-1, 1-5, 1-6, 1-7, and 1-8.

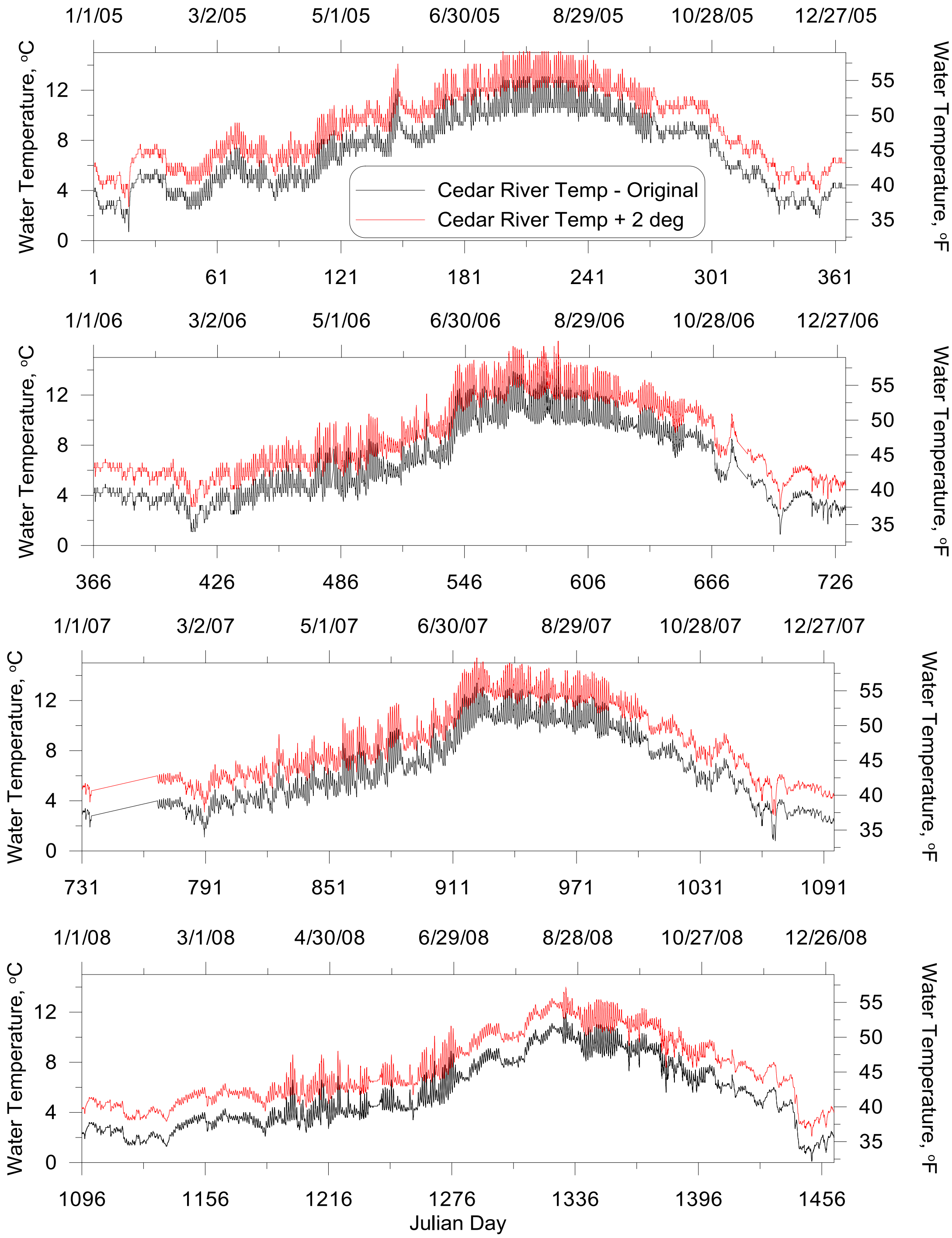

Figure 2. Cedar River temperatures, original and +2°C

Figure 3 shows an example of the 2 week earlier shift applied to all inflows to Chester Morse Lake for scenarios 1-4, 1-5, and 1-7.

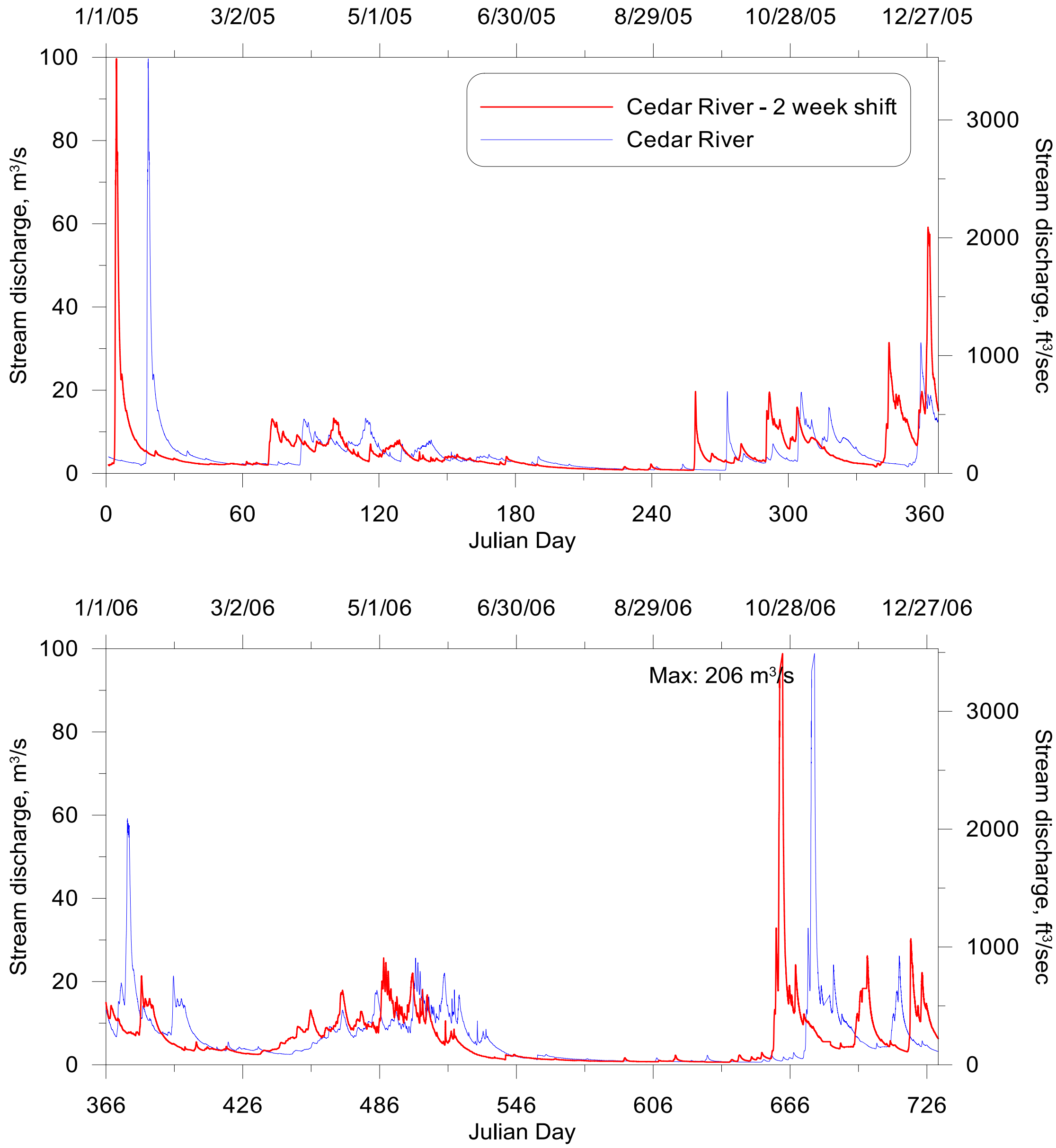

Figure 3. Cedar River flow, original and 2 week shift

These scenarios were run for the purpose of demonstrating the sensitivity and potential future uses of the Chester Morse Lake and Cedar River models. These scenarios could be adapted to capture other future scenarios, including snow pack changes, more dramatic climate changes or different water management approaches.

Scenario Results

Climate Change Scenarios

Each of the model scenarios were run for the same 4 year period as the calibration run, with adjustments in temperature or flow made to the original calibration input files. Figure 4 shows the % volume of optimal growth potential habitat for bull trout (just based on temperature criteria and hence does not include food availability) for Chester Morse Lake for the base case and each of the climate change scenarios.

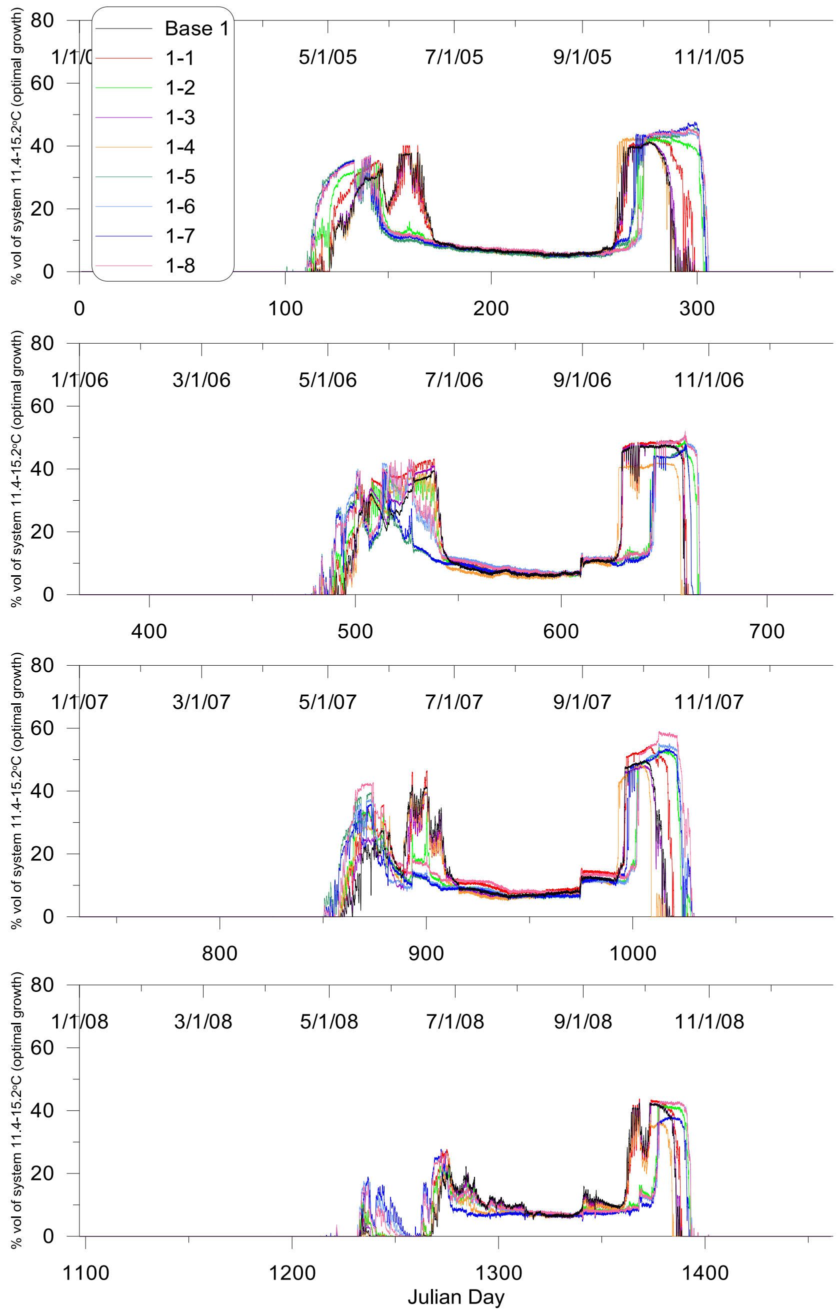

Figure 4. Optimal growth potential (11.4-15.2^{o}C) habitat volumes as % volume of full system – climate change scenarios

Figure 5 shows the % volume of high growth potential habitat for bull trout for Chester Morse Lake for the base case and each of the climate change scenarios.

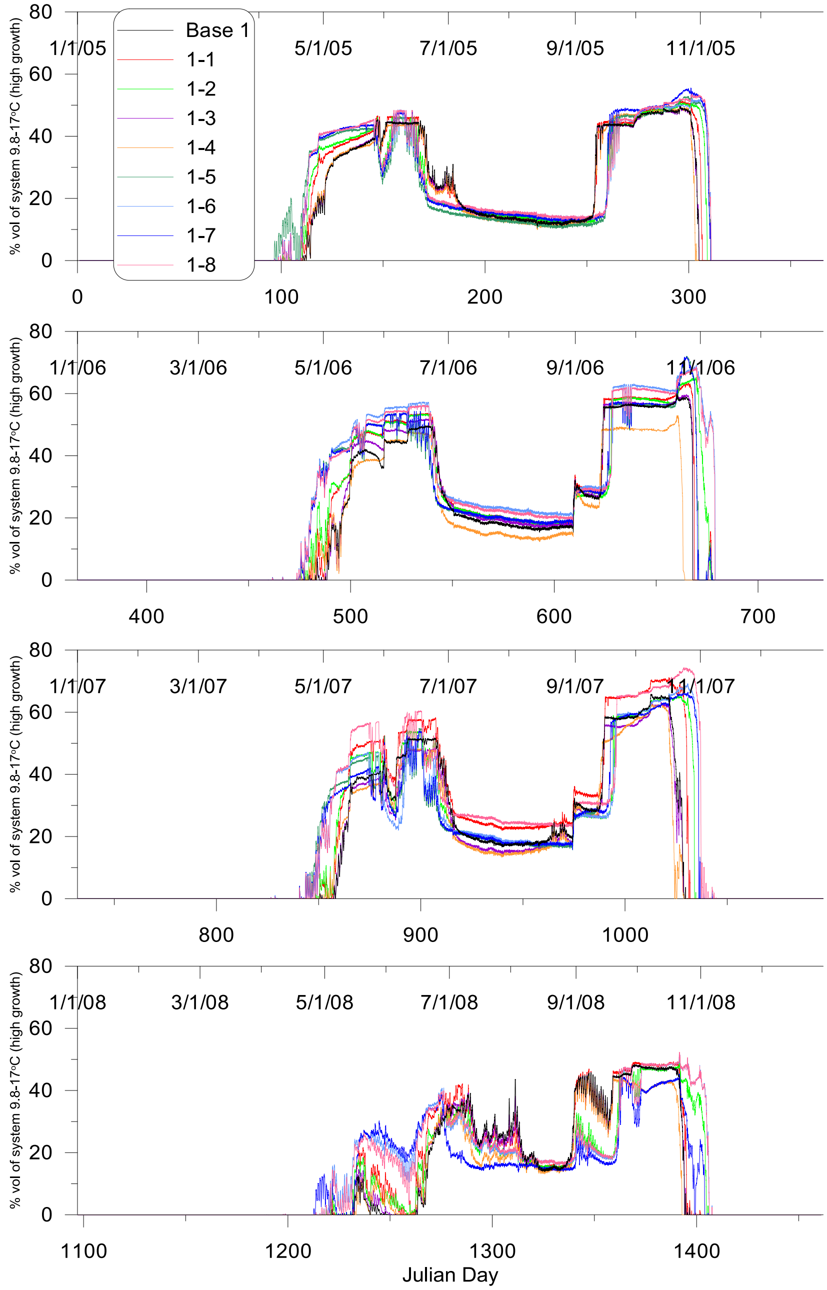

Figure 5. High growth potential (9.8-17°C) habitat volumes as % volume of full system – climate change scenarios

As can be seen from the above graphs, the impact of the climate change related meteorological and flow changes varies from year to year with changing weather conditions. Generally speaking, the volume of high growth potential habitat available for bull trout is the same or greater in most of the climate change scenarios than in the base case. However it can be observed that the timing of habitat availability does change. With increased temperatures such as when inflow temperatures are increased by 2°C, more habitat is available earlier in the spring and later into the fall than seen in base case. This is because most of the temperature related inhibition of growth potential is due to excessively cold temperatures. An enlarged image of ultimate fish habitat for the first year of the model run is shown in Figure 6.

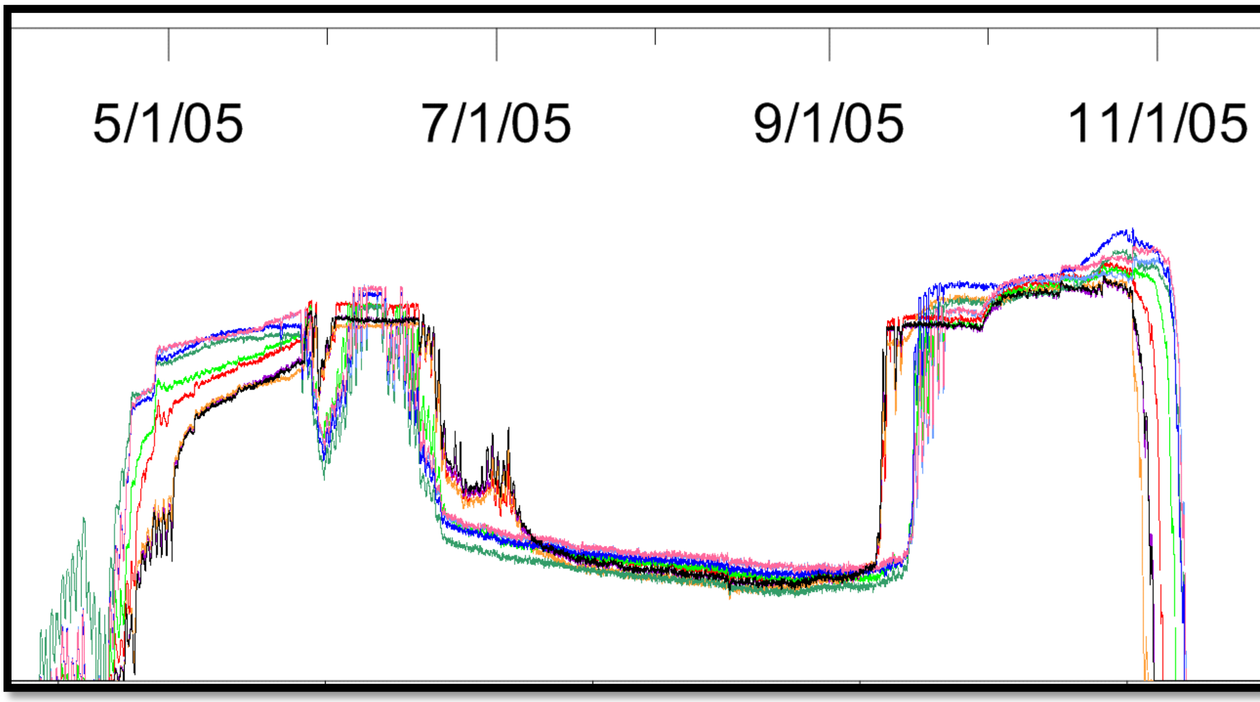

Figure 6. Close-up of ultimate fish habitat for 2005

As an example of this increased volume of optimal and high growth potential habitat during the early spring, the following figures show habitat zones on April 25, 2005 across all the climate change model scenarios. Figure 7 shows the fish habitat results of the base case. Figure 8 shows model run 1-1, which modeled an increase in inflow temperatures of 2°C. Table 2 defines the habitat zones used in the figures that follow.

Table 2. Fish Growth Potential Zones

Growth Potential Zones	Temperature Criteria
1 - Optimal Growth (more than 0.14 g/d)	11.4-15.2 °C
2 - High Growth (0.12-0.14 g/d)	9.8-17 °C
3 - Medium Growth (0.10-0.12 g/d)	8.7-18 °C
4 - Low Growth (less than 0.10 g/d)	6-20 °C
5 - Non-lethal (no growth)	0-26.4°C

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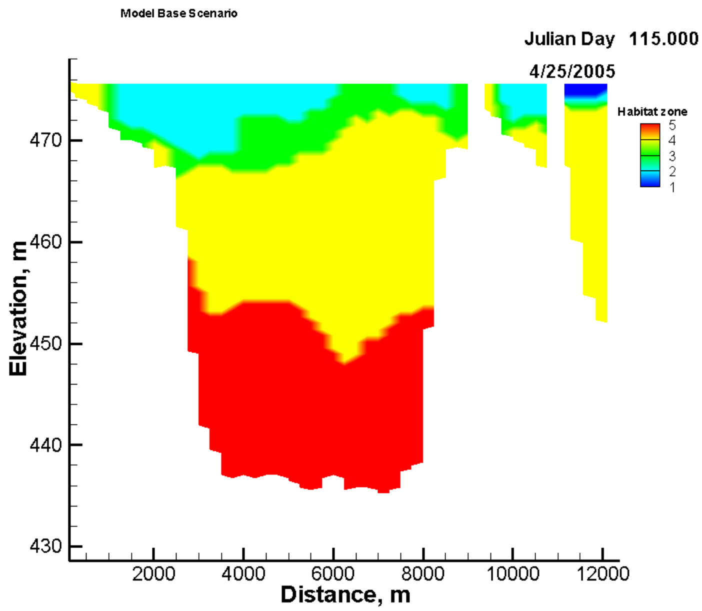

Figure 7. Bull trout habitat – base case, 4/25/2005

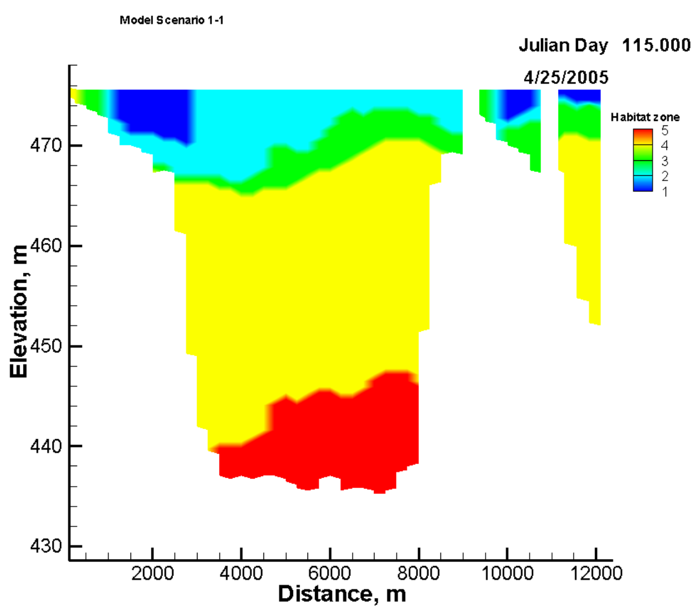

Figure 8 Bull trout habitat – case 1-1, 4/25/2005

Figure 9 shows case 1-2 which models a 2°C increase in air temperature. Figure 10 shows case 1-3 which models a decreased flow rate of 10%.

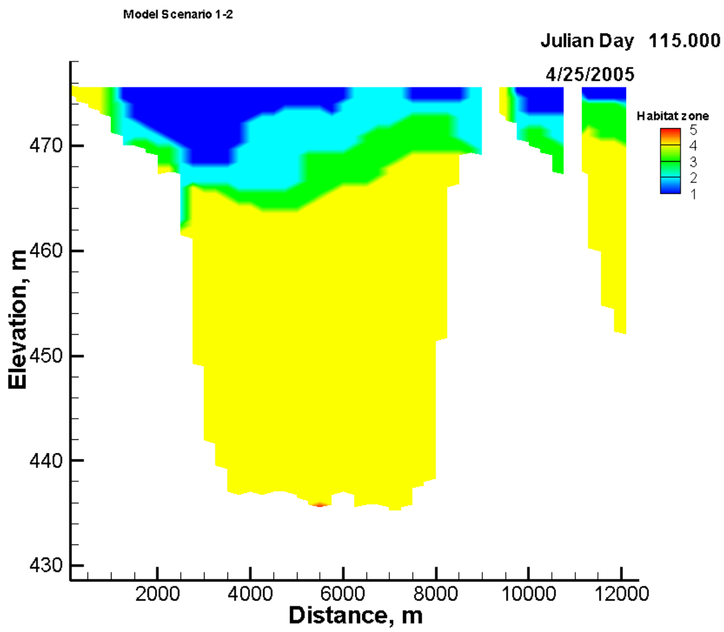

Figure 9 Bull trout habitat – case 1-2, 4/25/2005

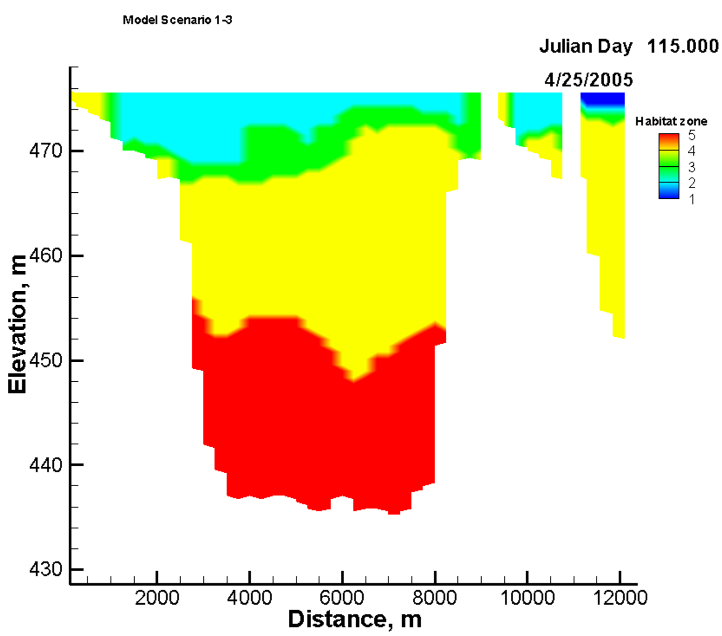

Figure 10 Bull trout habitat – case 1-3, 4/25/2005

Figure 11 shows case 1-4 which models a two week inflow shift. Figure 12 shows case 1-6 which models increased inflow water temperatures and air temperatures of 2°C and decreased inflow rates of 10%.

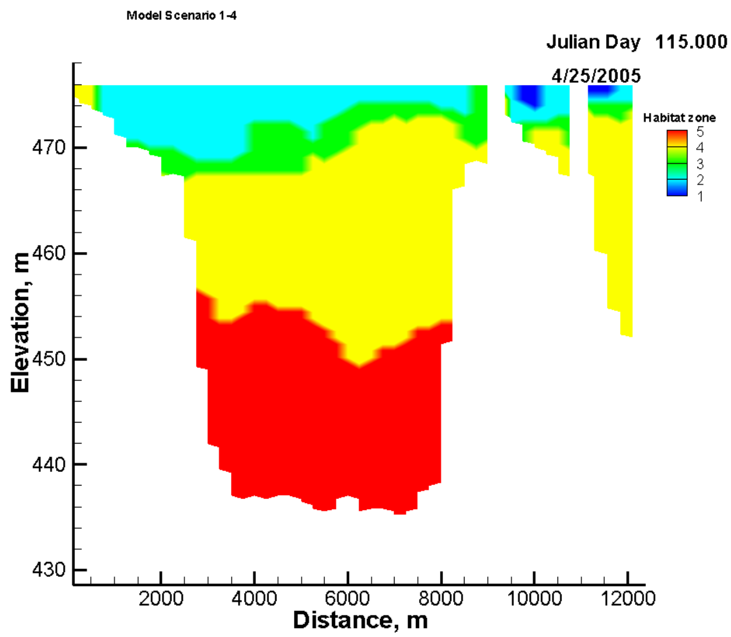

Figure 11 Bull trout habitat – case 1-4, 4/25/2005

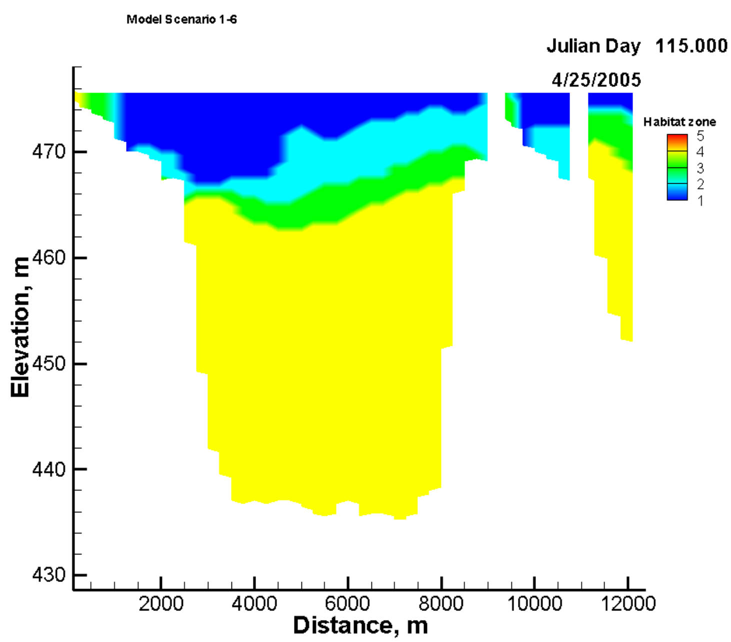

Figure 12 Bull trout habitat – case 1-6, 4/25/2005

Figure 13 shows case 1-7 which models increased inflow water temperatures and air temperatures by 2^{o}C and 2 week shift earlier of inflows. Figure 14 shows case 1-8 which models increased inflow water temperature and air temperature by 2^{o}C.

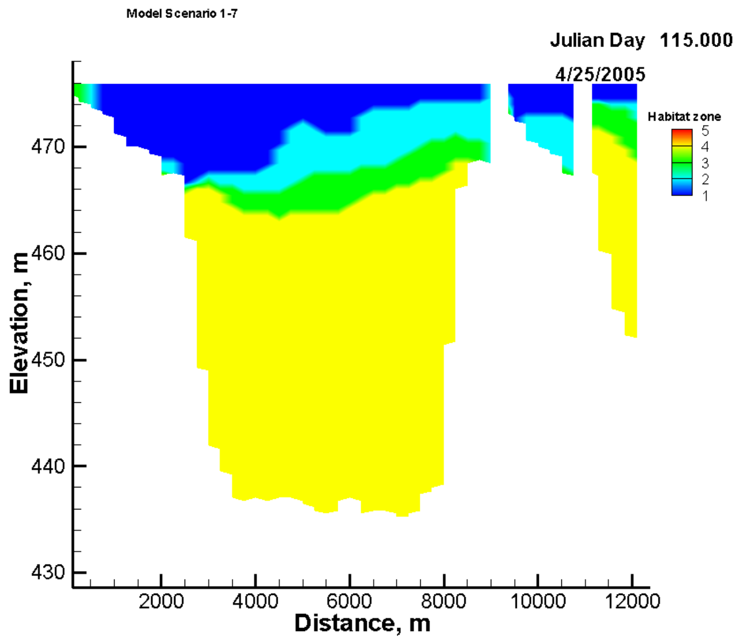

Figure 13 Bull trout habitat – case 1-7, 4/25/2005

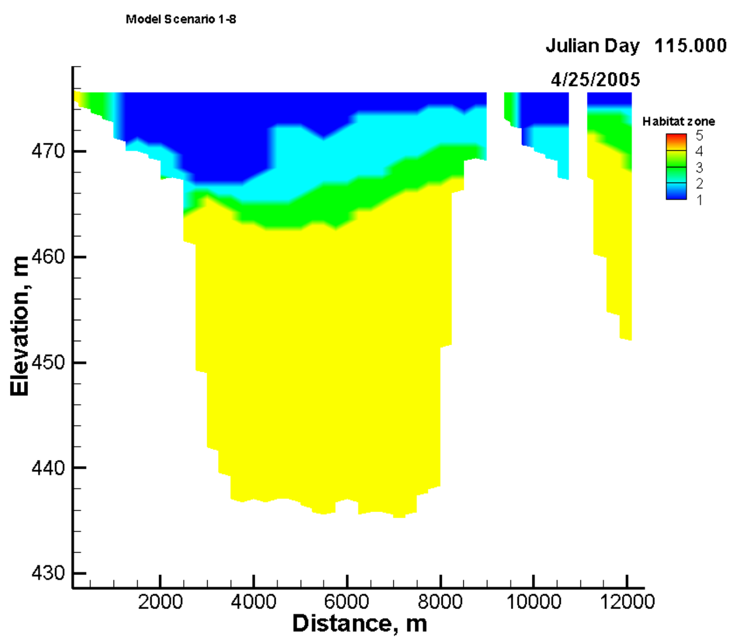

Figure 14 Bull trout habitat – case 1-8, 4/25/2005

Scenarios 1-1 and 1-2 indicated that warmer inflow or air temperatures result in an increase in favorable thermal habitat for bull trout in the early spring. Scenarios 1-3 and 1-4 do not result in any significant change from base case, hence it can be concluded that a 10% decrease in inflows (still operated at historic lake levels, so depths do not change) or a 2 week shift to earlier inflows will not significantly impact bull trout thermal habitat. The greatest impact to thermal conditions is seen when combining an increase in air and water inflow temperatures as seen in the final 3 scenarios, 1-6, 1-7, and 1-8. There is relatively little difference between these scenarios indicating that flow timing and quantity isn't as significant a factor as climatic temperature changes.

Water Management Scenarios

The water management scenarios were run using the meteorological and boundary condition data from the 4-year calibration period. In these model scenarios, the water levels in the masonry pool were managed to match recorded water elevations during the calibration period.

Figure 15 shows the water elevation in the main lake for the base case and the three water management scenarios. Water levels under high water conditions are very similar, and diverge only when water levels drop below 475 meters.

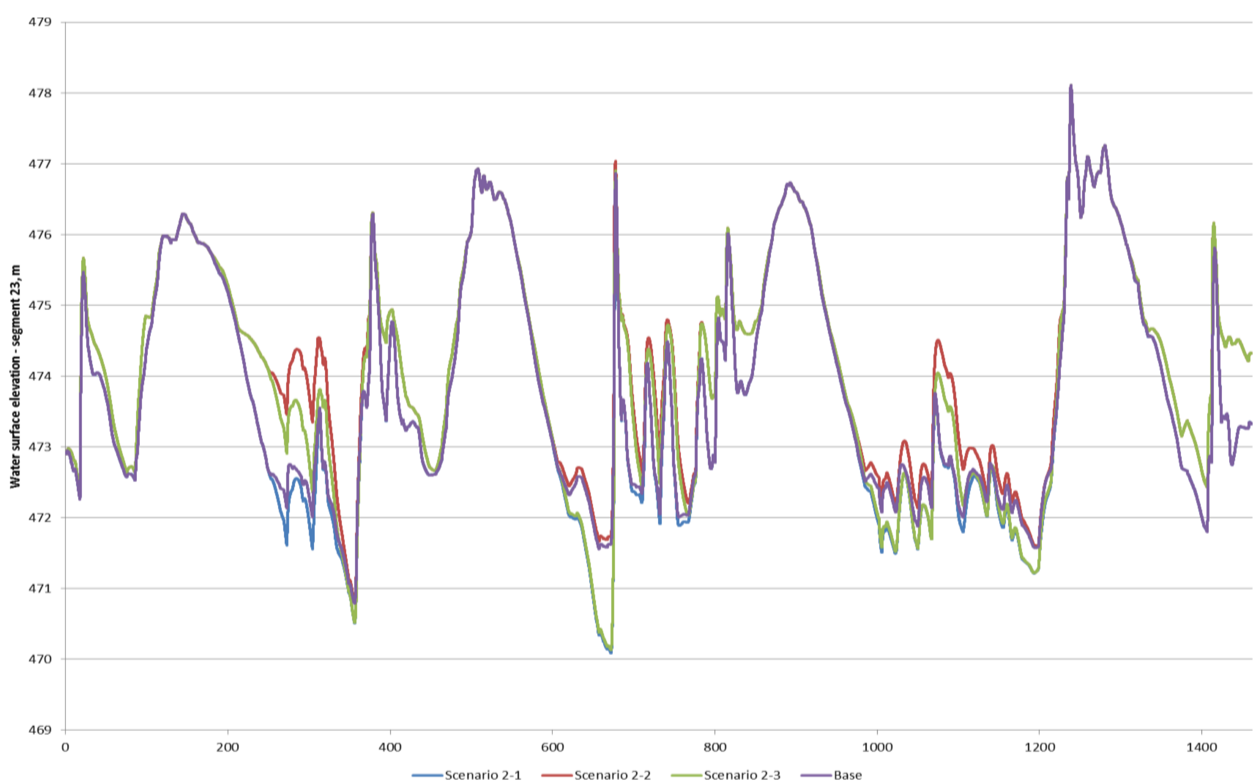

Figure 15. Water level graph for water management scenarios

Figure 16 shows the % volume of optimal growth potential habitat for bull trout (based only on temperature criteria and hence it does not include food availability) for Chester Morse Lake for the base case and each of the three water management scenarios.

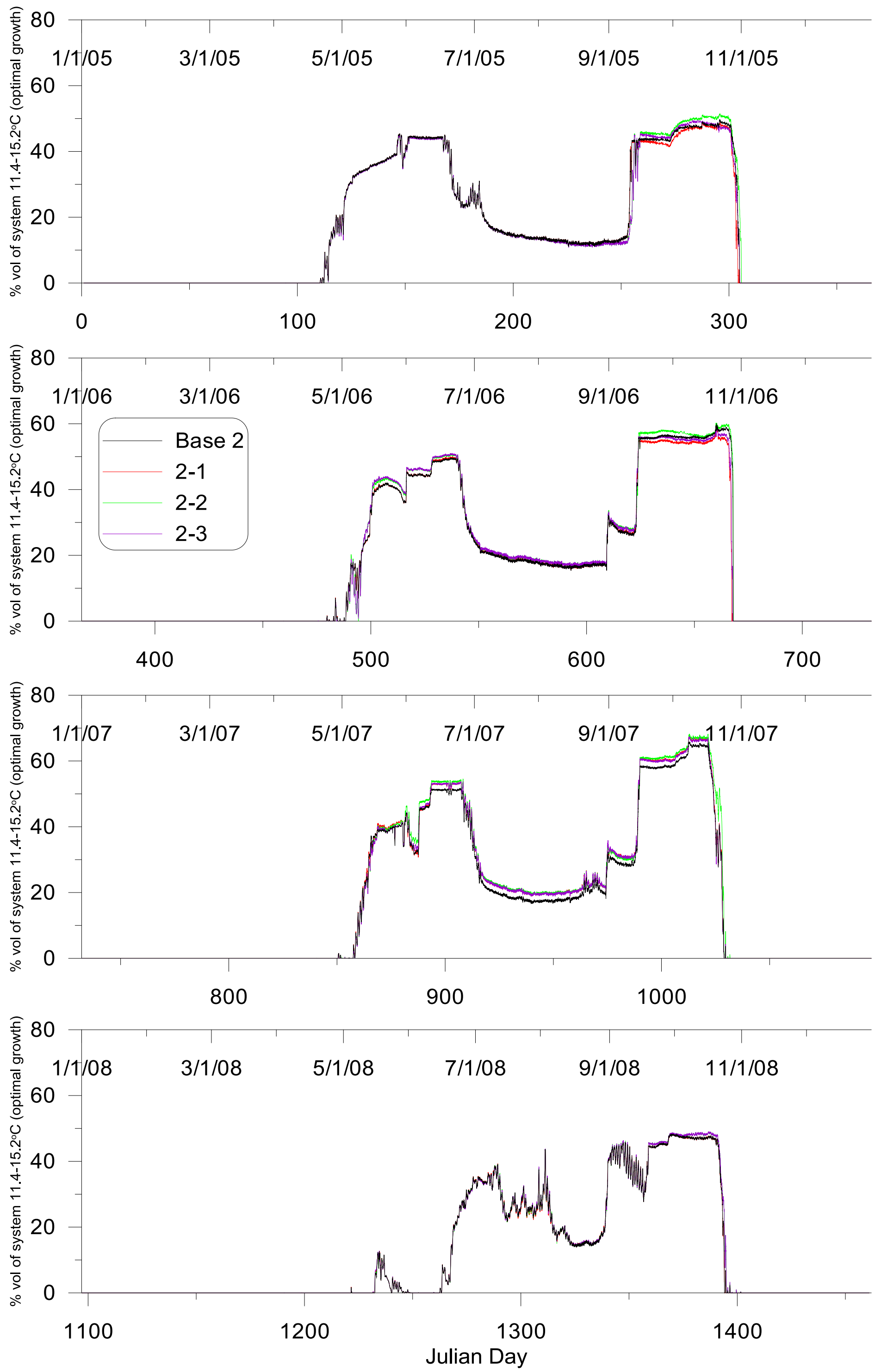

Figure 16. Optimal growth potential (11.4-15.2°C) habitat volumes as % volume of full system – water management scenarios

All four scenarios show fairly similar thermal behavior over the four year period. Some variation is seen in late fall, mostly due to the increased storage potential later into the year for some of the scenarios.

Figure 17 shows fish habitat for the base case scenario for 10/23/2006. Figure 18 shows case 2-1 which models increased drawdown by switching on pumps between the main lake and Masonry Pool.

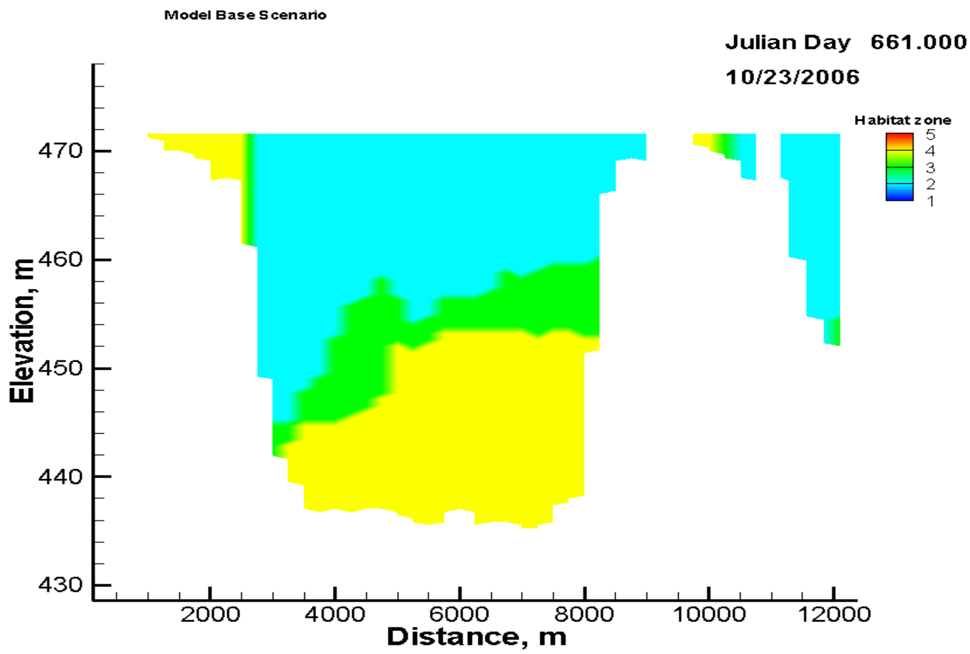

Figure 17. Bull trout habitat – base case, 10/23/2006

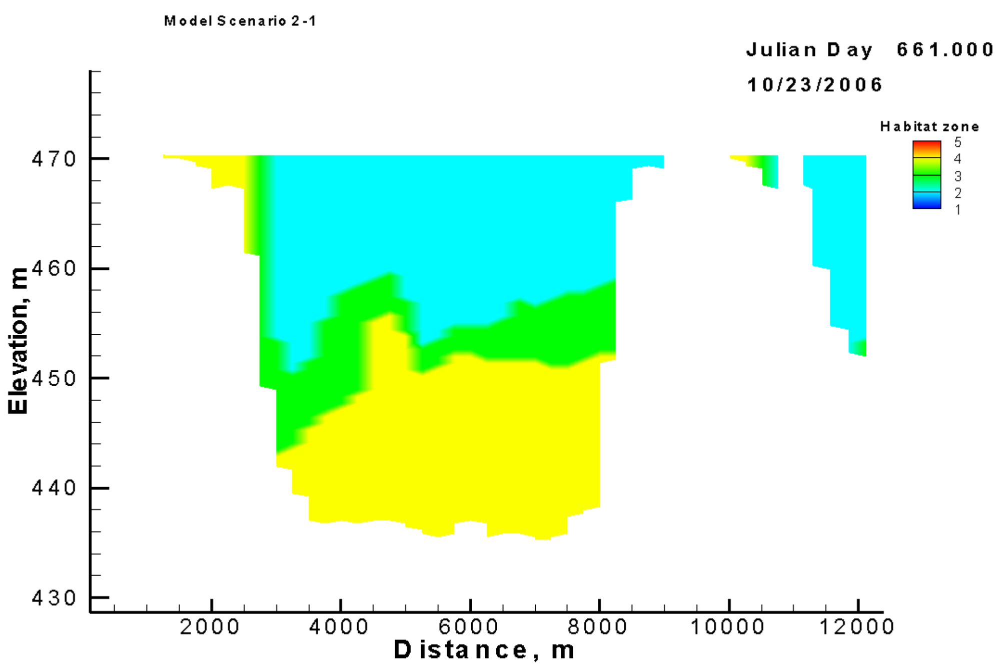

Figure 18. Bull trout habitat – case 2-1, 10/23/2006

Figure 19 shows case 2-2 which models increased storage by increasing the elevation of the flashboard dam by 2 meters. Figure 20 shows case 2-3 which models both increased drawdown and flashboard dam elevation.

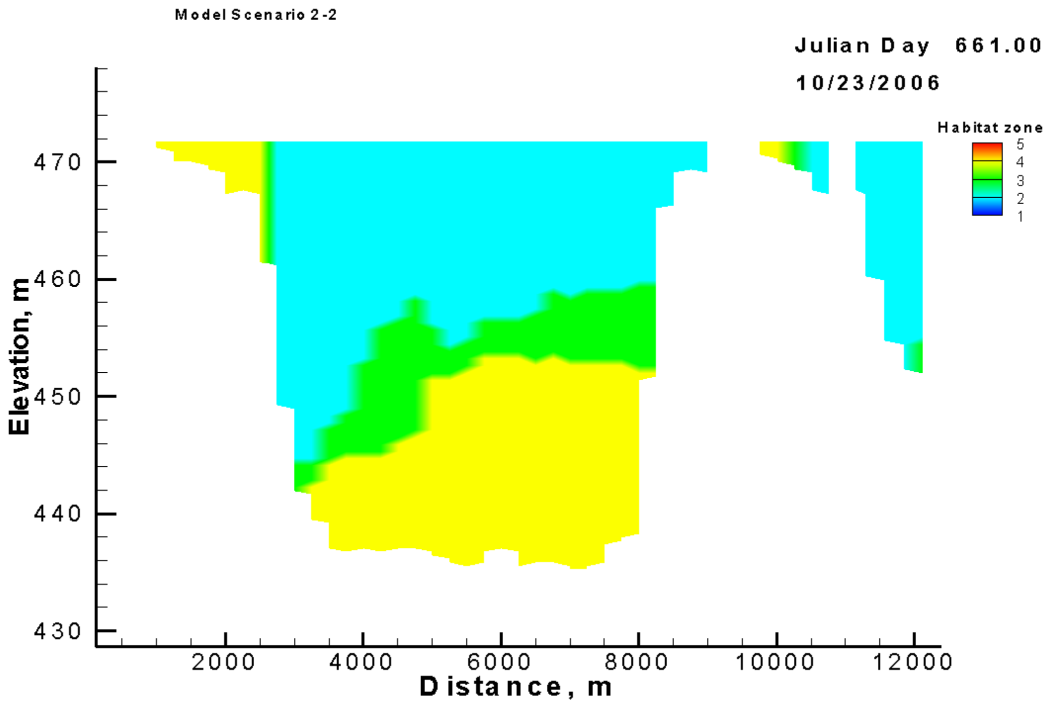

Figure 19. Bull trout habitat – case 2-2, 10/23/2006

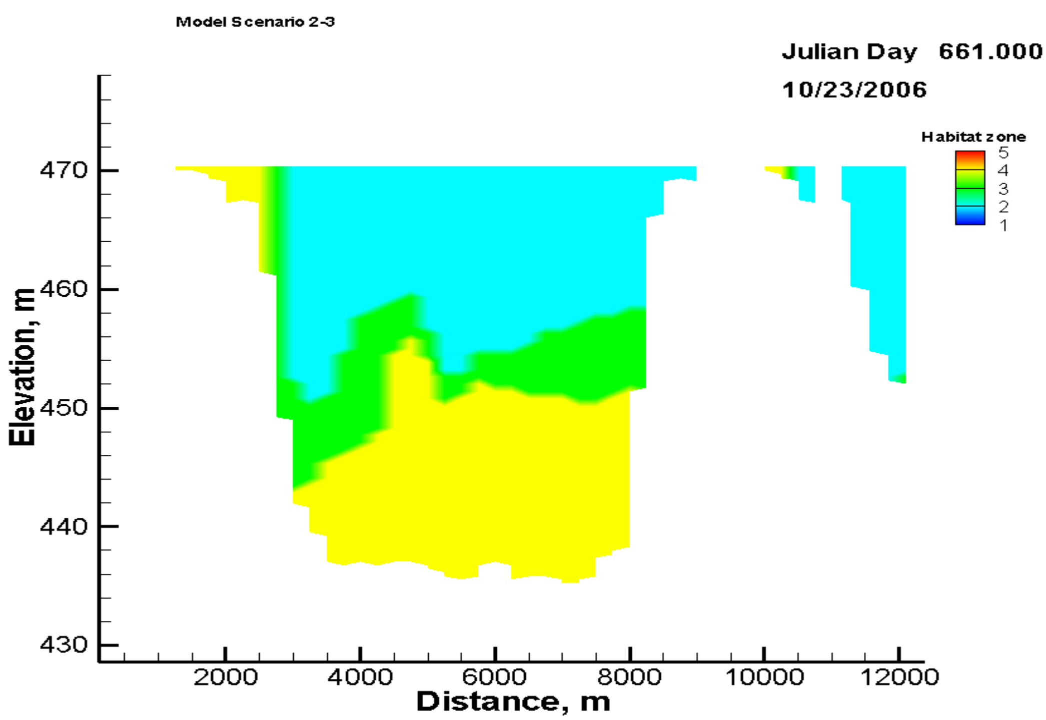

Figure 20. Bull trout habitat – case 2-3, 10/23/2006

As the previous figures illustrate, there is very little thermal difference between these water management scenarios. The changes (2 meter flashboard height increase, pumping rate of 2 m^3/sec) are not drastic and would be unlikely to significantly impact bull trout habitat in the lake. Increased pumping rates or larger changes in reservoir elevation might have more pronounced effects.

Natural Lake Scenario

In an attempt to determine how construction of the Masonry and Flashboard dams have impacted bull trout habitat in Chester Morse Lake, a "natural" scenario was developed in which the natural lake elevation of 466 meters was restored. This cut off the Masonry Pool and reduced the number of model segments from 65 to 53. The natural case model scenario was run for the calibration period with the same input files as were used for the base case. Figure 28 shows the % volume of optimal growth potential habitat for bull trout for Chester Morse Lake for the base case and natural lake scenario.

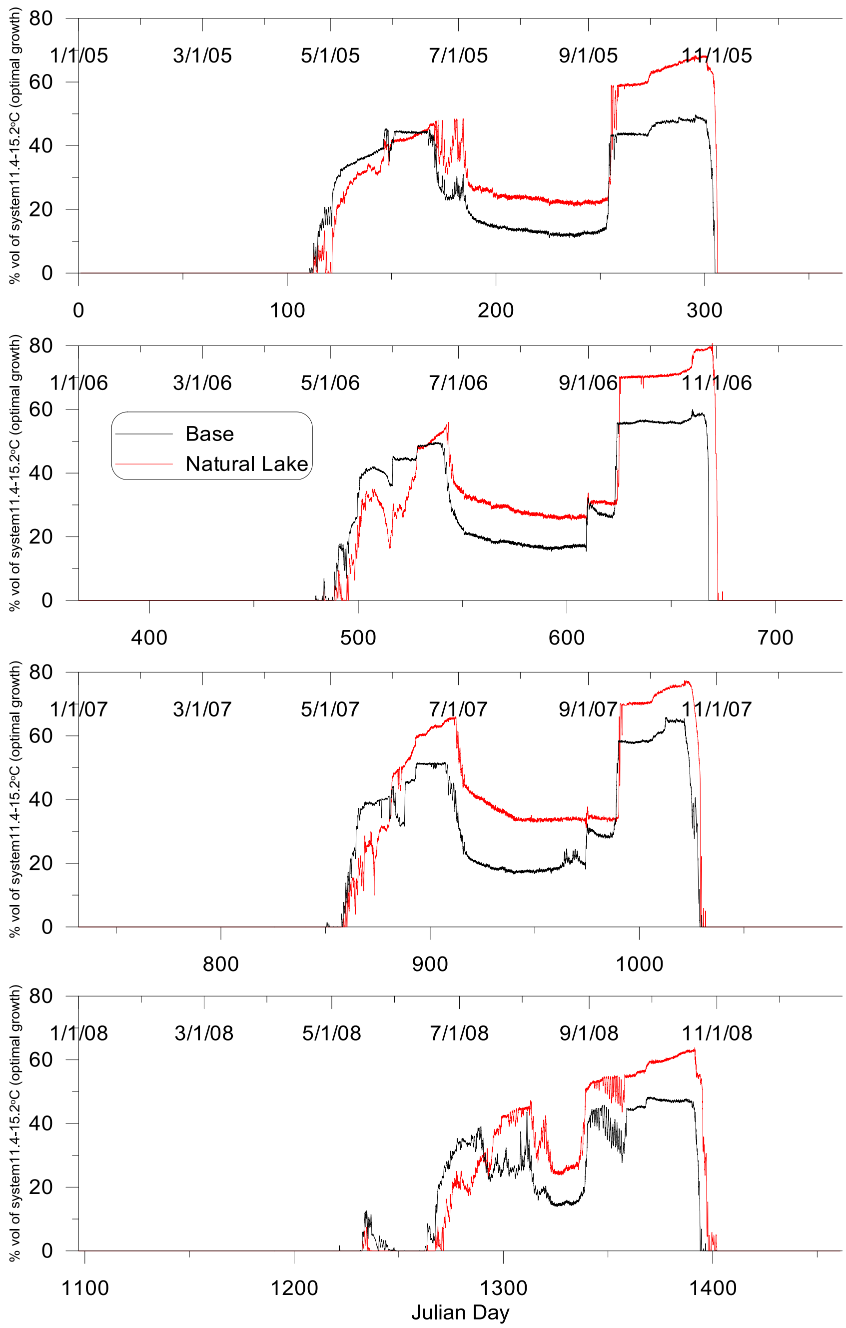

Figure 21. Optimal growth potential (11.4-15.2°C) habitat volumes as % volume of full system – natural lake

The differences shown in the previous figure between bull trout habitat in the base case and natural lake scenario are pronounced. It is important to remember, however, that these are percentages of total volume. The total volume of the natural lake is much smaller, so although a higher percentage of its volume has optimal thermal conditions, the total volume available to fish is smaller.

To demonstrate this difference visually, the following figures show several dates from both the model runs. Figure 22 shows fish habitat for the base case on 5/29/2005. Figure 23 shows habitat results from the same day and time for the natural lake scenario.

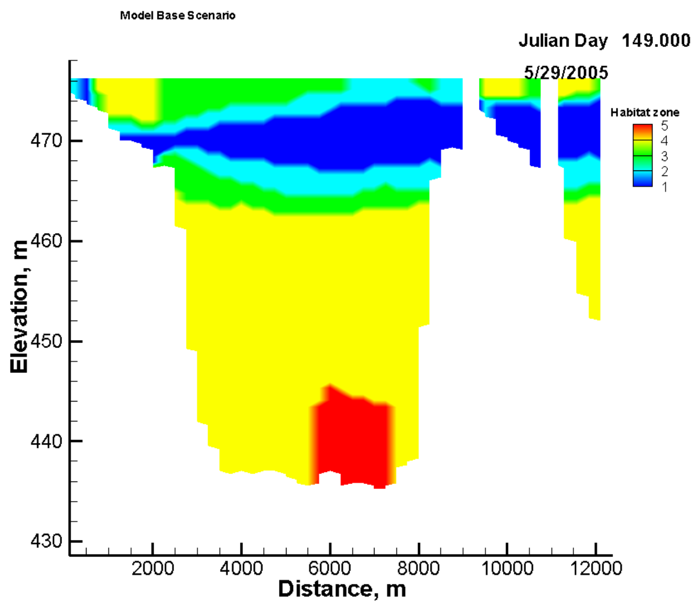

Figure 22. Bull trout habitat – base case, 5/29/2005

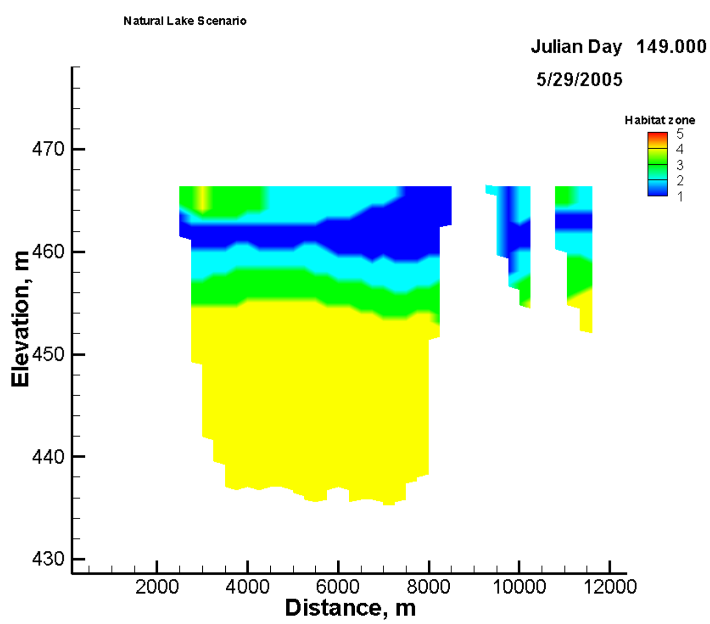

Figure 23. Bull trout habitat – natural case, 5/29/2005

Figure 24 shows fish habitat results for 8/27/2005 for the base case. Figure 25 shows similar results for the natural lake scenario.

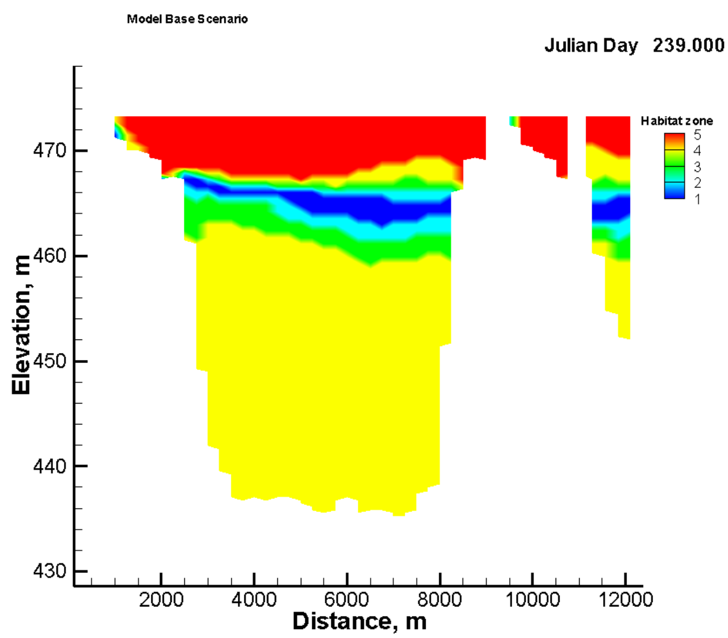

Figure 24. Bull trout habitat – base case, 8/27/2005

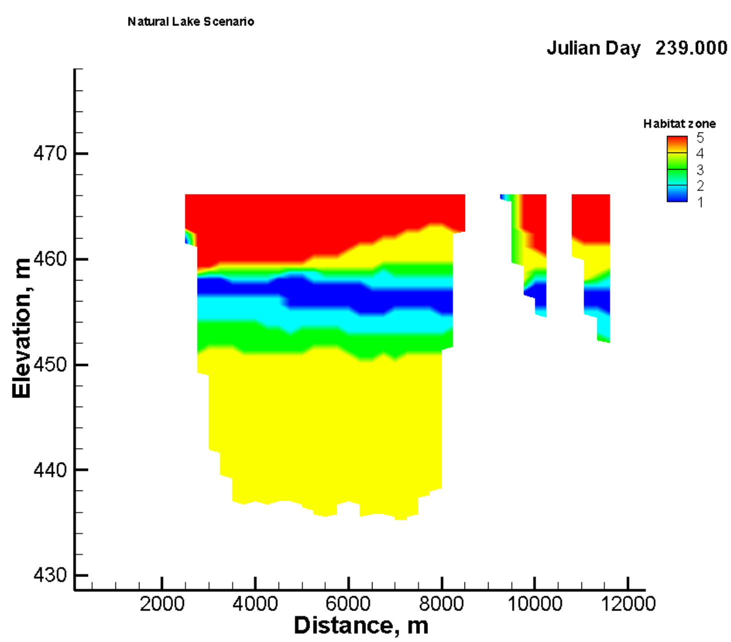

Figure 25. Bull trout habitat – natural case, 8/27/2005

The proceeding figures show that under natural conditions, a larger percentage of the lake is thermally favorable for bull trout. Optimal conditions are located closer to the bottom of the lake, which might be a more favorable condition, depending on the current food source for the bull trout.

In addition to affecting the thermal conditions in Chester Morse Lake, the natural lake condition results in different conditions downstream in the Cedar River. Both the temperature and flows released into the Cedar River are impacted considerably by the presence of the Masonry and flashboard dams. Figure 26 shows the outflow temperature of water released into the Cedar River from the base case scenario and the natural lake scenario.

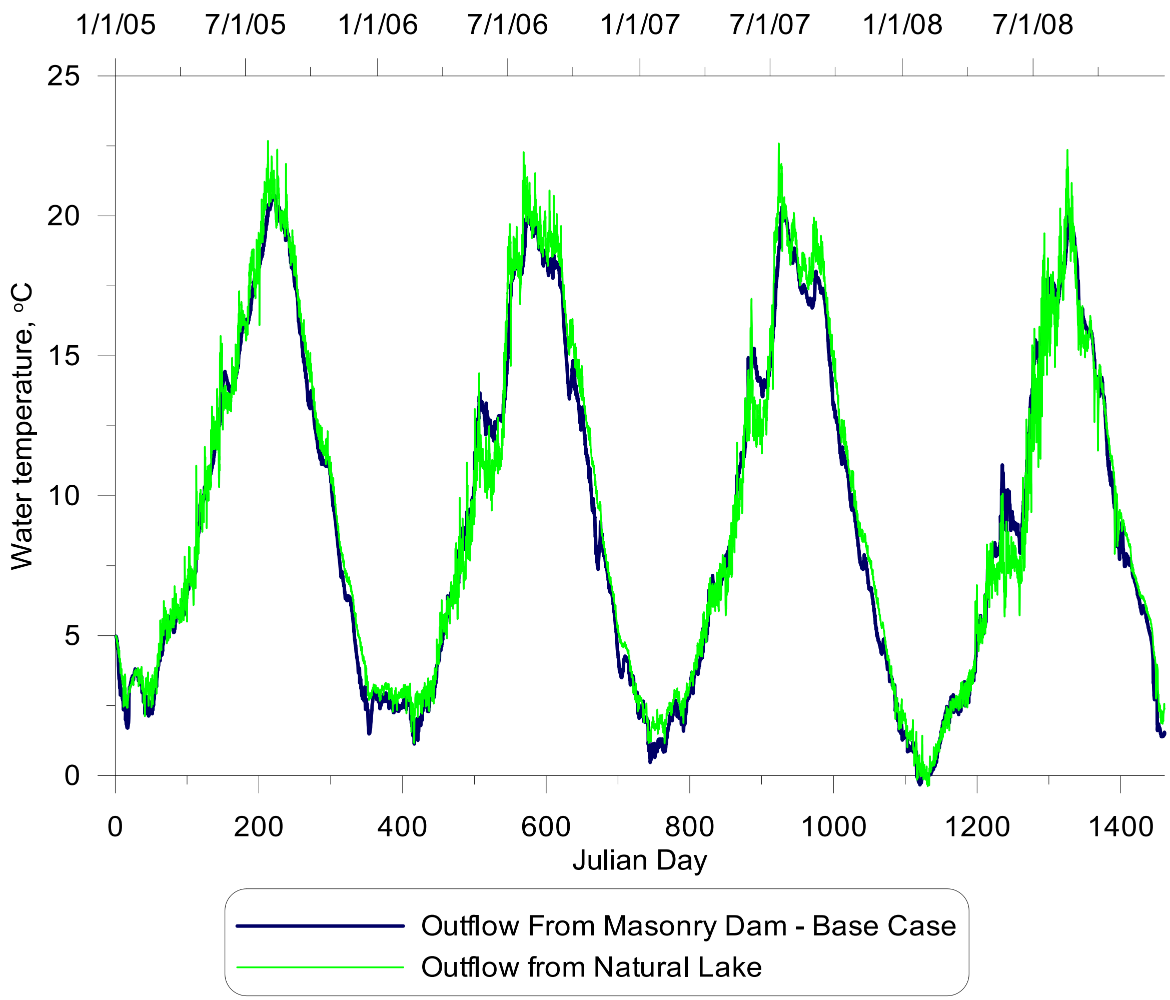

Figure 26. Outflow temperatures into the Cedar River – base case and natural lake scenario

Under natural conditions, spring release temperatures are cooler. Summer and fall temperatures in the natural river are warmer than for the base case. This is due to the fact that cooler water is released from deeper in the reservoir in the base case scenario.

Figure 27 shows the outflows from Chester Morse Lake into the Cedar River for the base case and natural lake scenarios.

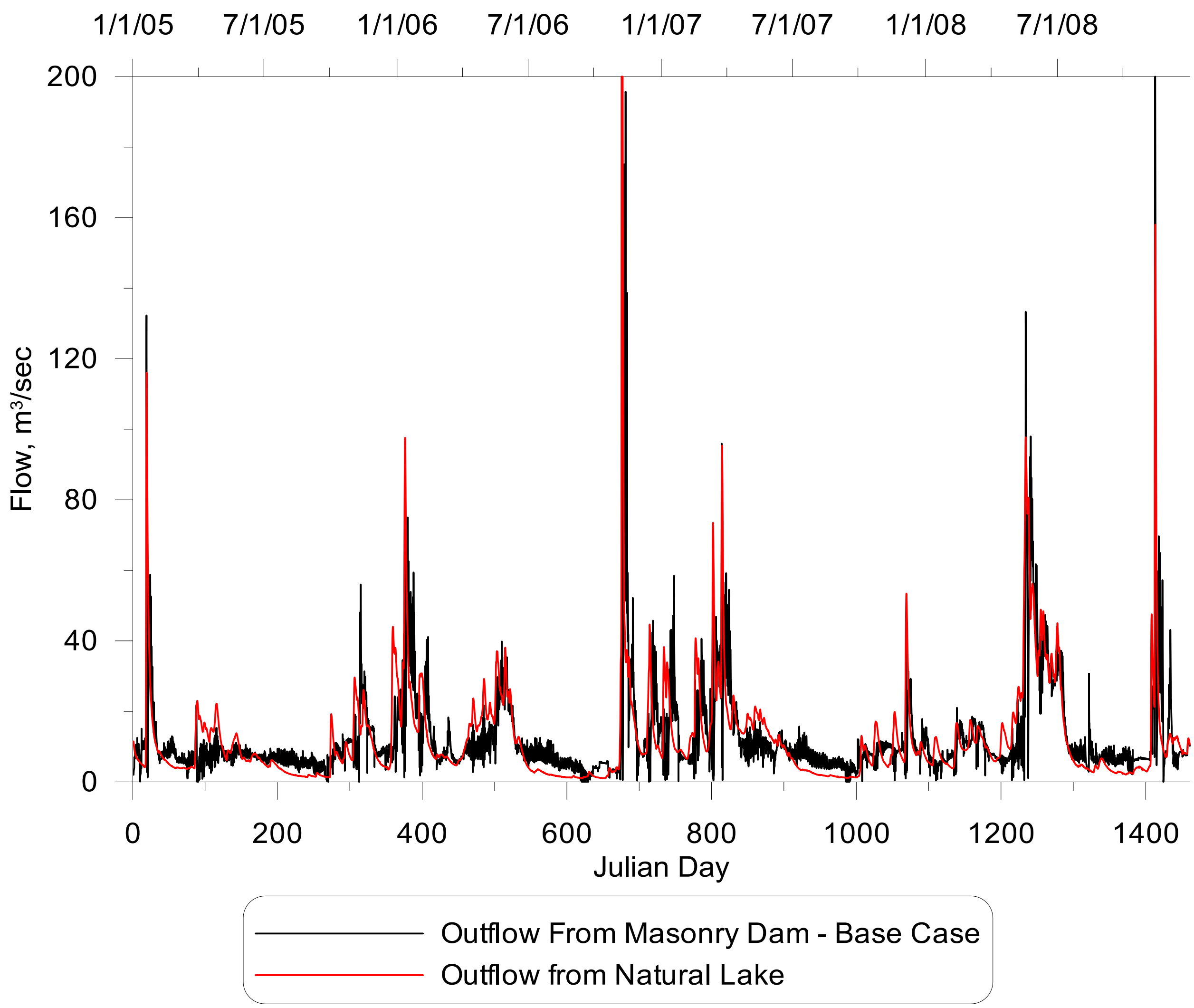

Figure 27. Flow rates into the Cedar River from the base case and natural lake scenario

As can be seen from the graph, natural flows are often flashier and higher during the spring runoff period. Flows during the summer and early fall period are much lower, since the natural lake does not have the storage potential of the dammed system as in the base case.

Summary

The Chester Morse Lake Model (Wells and Wells, 2011) was used to evaluate potential climate changes, management changes in the operation of the lake, and the natural lake condition. The results of these simulations were evaluated based on temperature habitat conditions in the lake. Evaluations could also have been made of temperatures in the Cedar River system.

Figure 28 and Figure 29 summarize the fish habitat results between the various model scenarios, as percentage of total volume of the main lake, and as volume of the main lake, respectively. The Masonry Pool was not used in these volumes or percentages. These figures reflect averages over the 4 year model period.

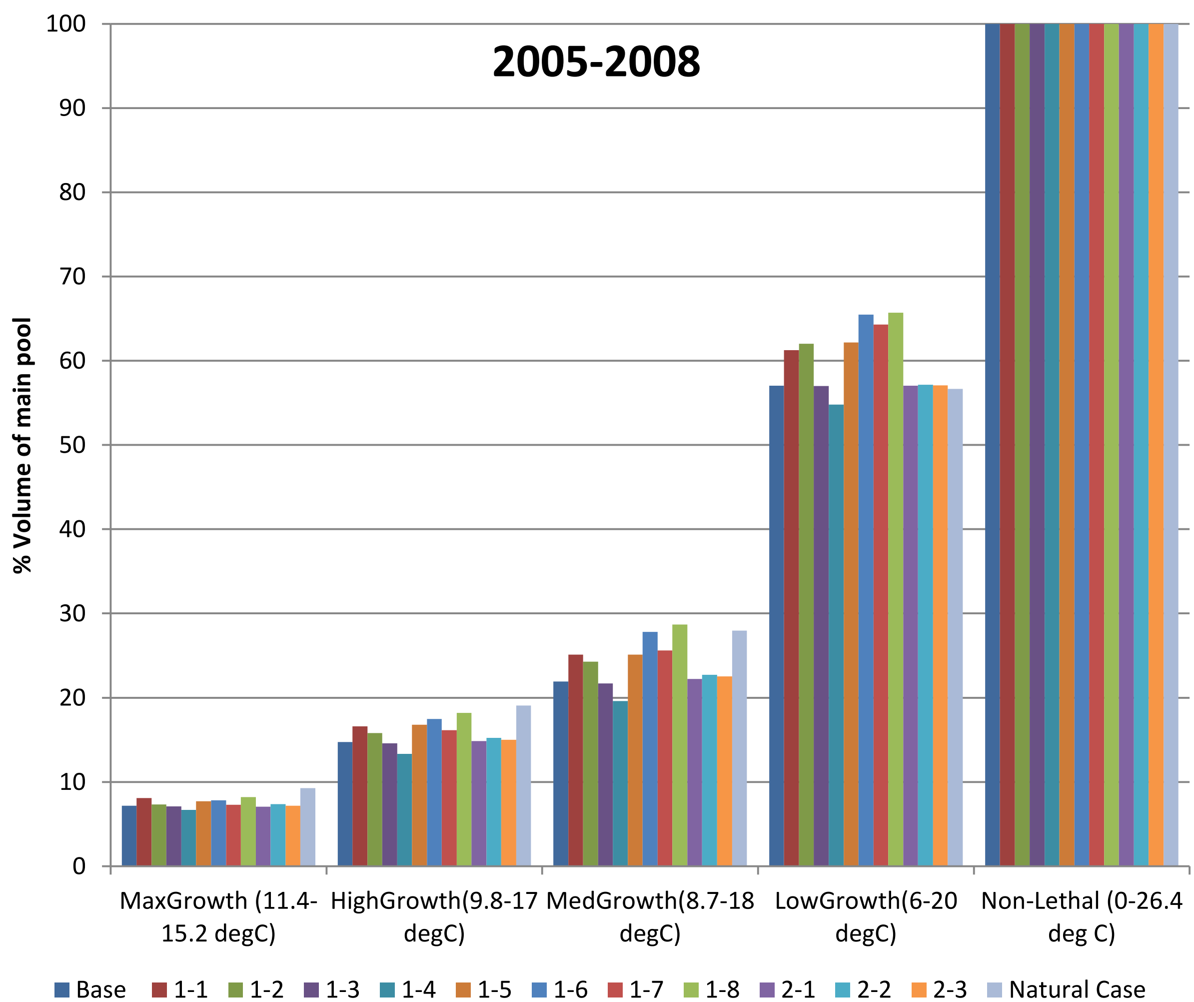

Figure 28. Summary of fish habitat by % volume – all scenarios – average over 4-year model period

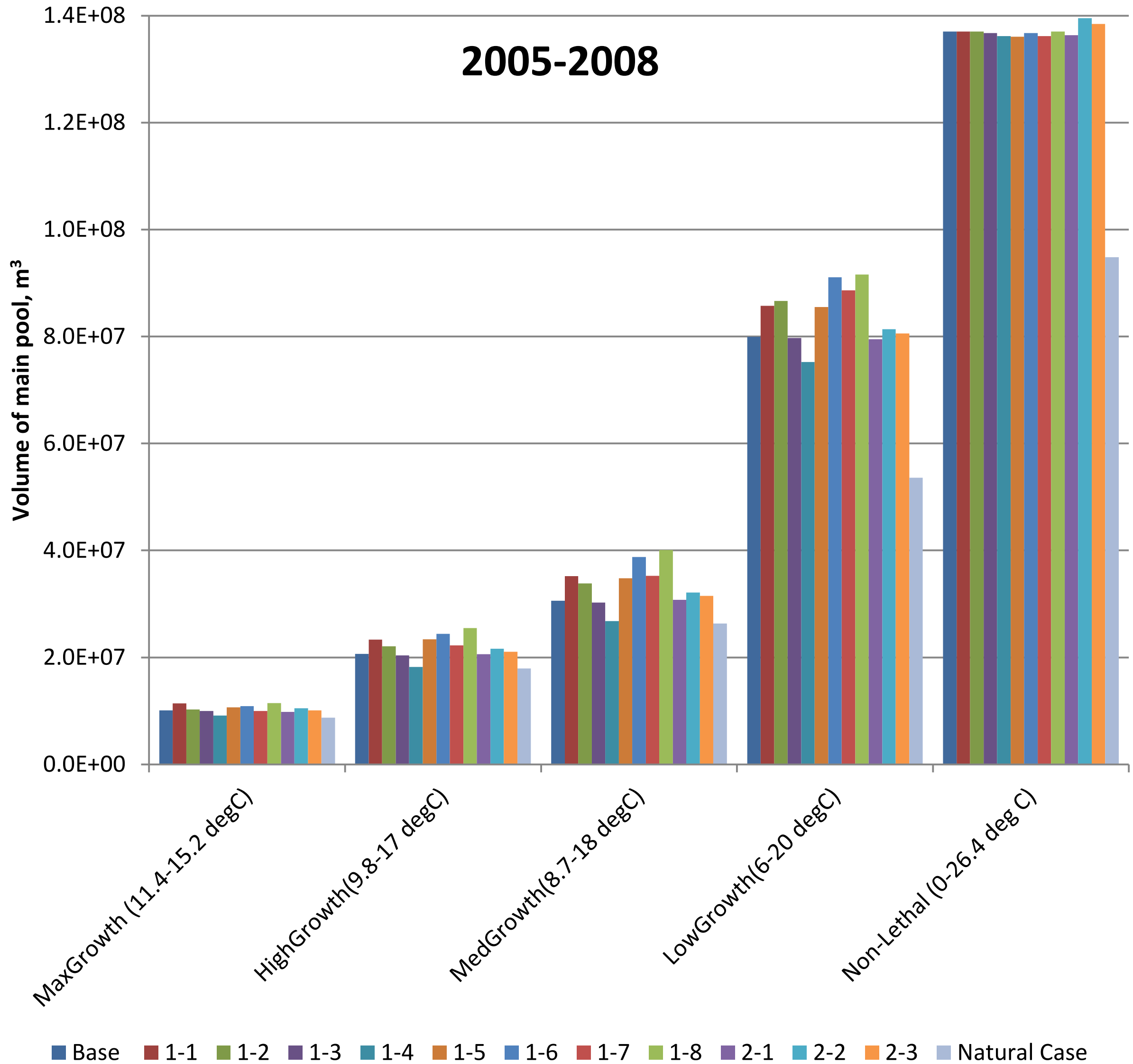

Figure 29. Summary of fish habitat by volume – all scenarios – average over 4-year model period

Results between years show some variability between the model scenarios. Two years, 2005 and 2008 are shown separately in Figure 30, Figure 31, Figure 32, and Figure 33, first as percent volume and then as total volume.

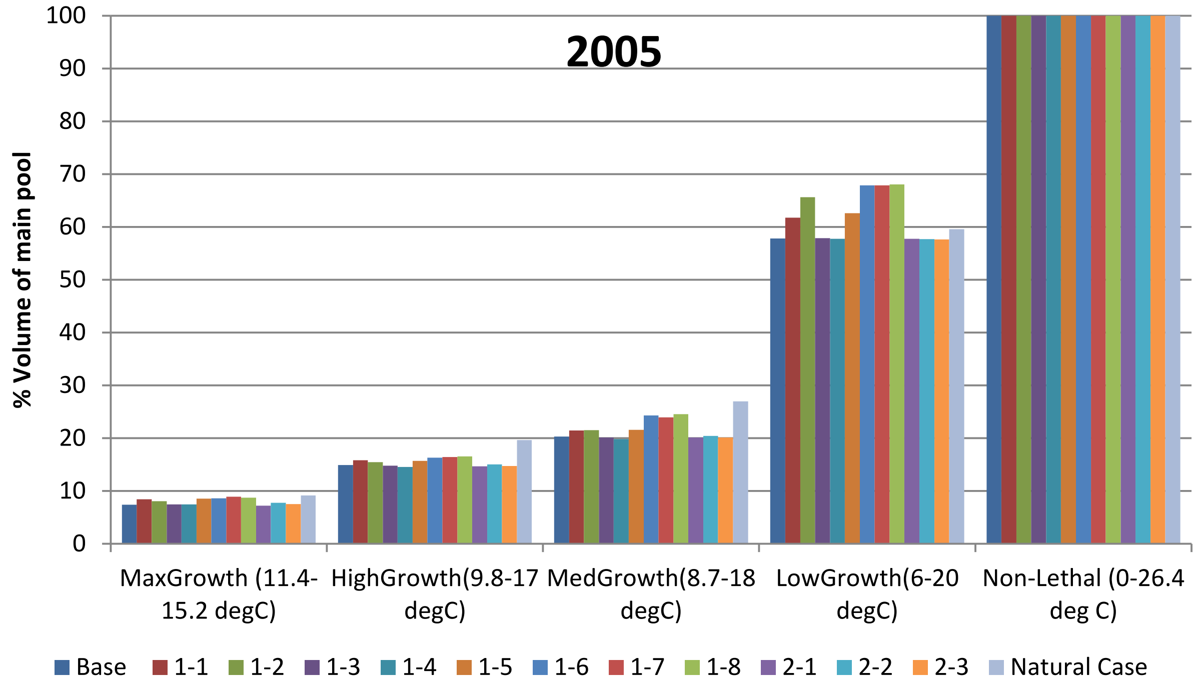

Figure 30. Summary of fish habitat by % volume – all scenarios – average for 2005

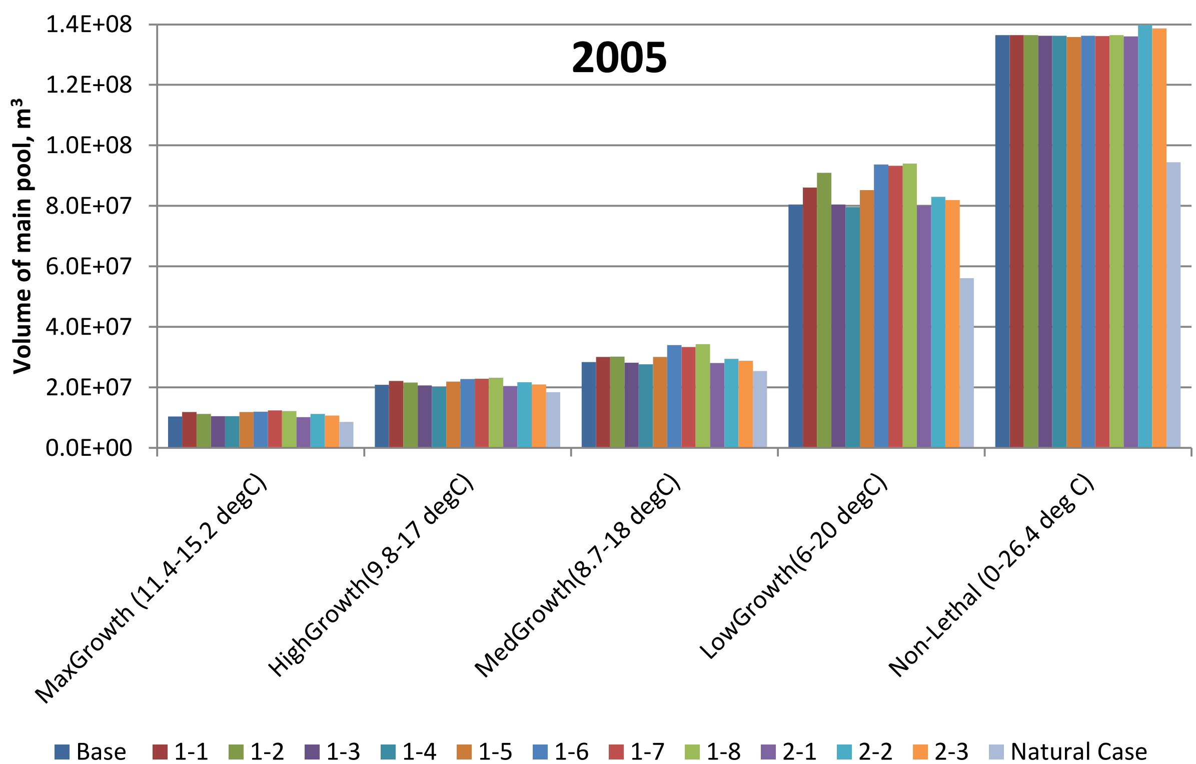

Figure 31. Summary of fish habitat by volume – all scenarios – average for 2005

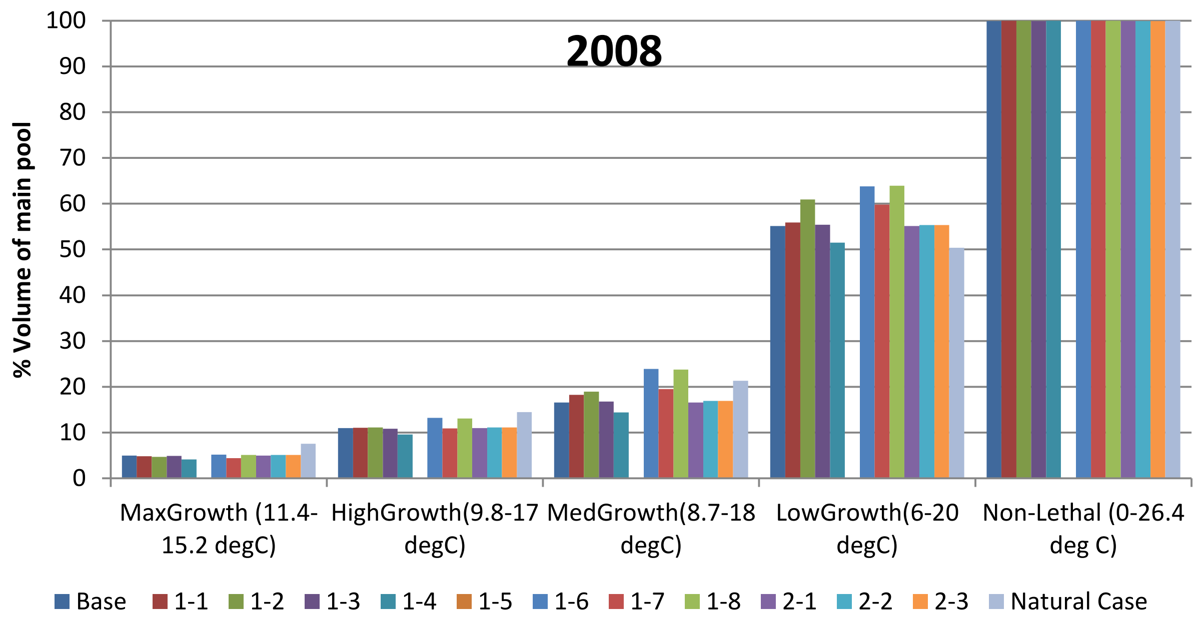

Figure 32. Summary of fish habitat by % volume – all scenarios – average for 2008 (Note: some values are missing for 1-5)

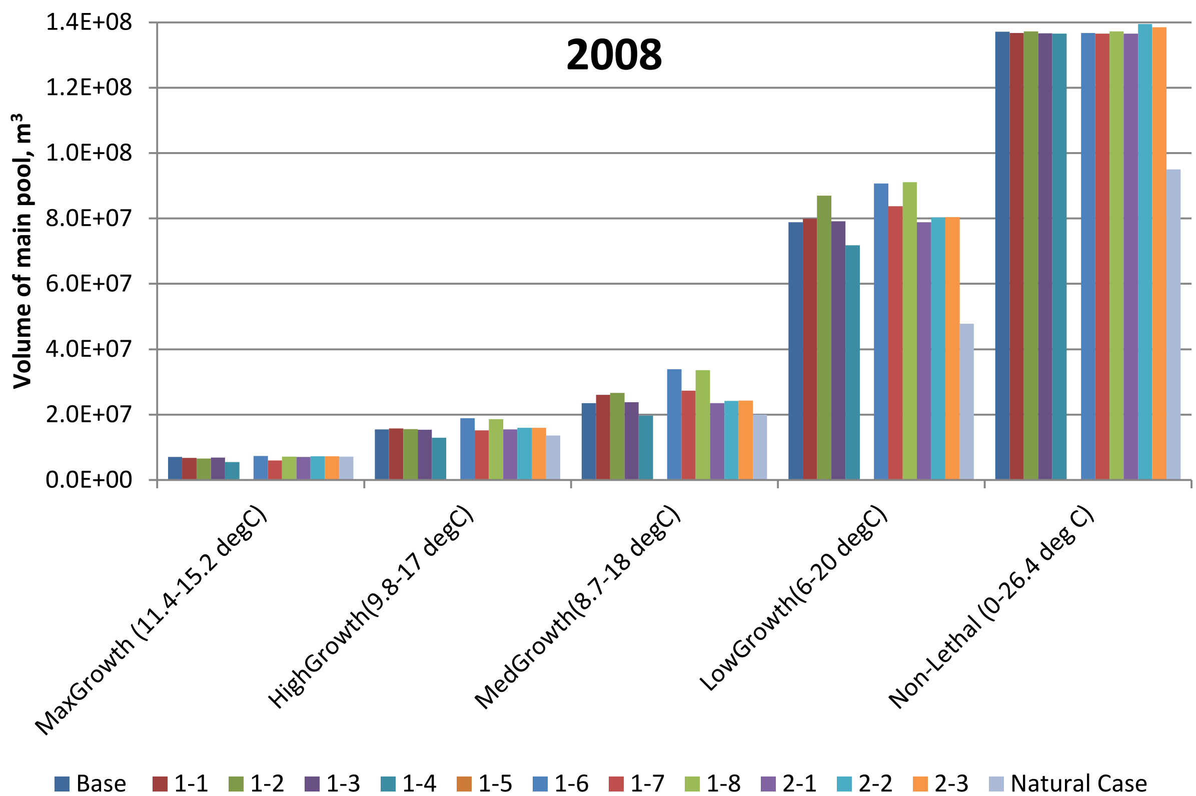

Figure 33. Summary of fish habitat by volume – all scenarios – average for 2008 (Note: some values are missing for 1-5)

2005 is an example of a fairly average year in terms of thermal conditions for bull trout. 2008 is a more stressful thermal year due to very cold spring temperatures. Comparing these two years shows that differences between the model scenarios vary in magnitude between years depending on the prevailing weather and hydrologic conditions.

The results indicate that given small weather or management changes, the thermal regime of Chester Morse Lake is unlikely to be severely impacted. It is reasonable to conclude that the thermal habitat available to bull trout will not be dramatically changed on an average annual basis even though there can be larger differences in timing as a result of the scenarios considered and hydrology and meteorological conditions. This does not, however, address the possible impact of climate change or water management scenarios on food availability. The final natural case does indicate that the construction of the Masonry Dam and flashboard dam have had a significant impact on bull trout habitat. Although the total volume of optimal or high growth potential habitat is less under the natural scenario, a larger portion of the lake has thermal conditions favorable to bull trout. It is possible that these conditions gave them easier access to food sources while remaining in thermally favorable conditions.

References

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