YUKON ENERGY

Hydraulic Modelling of Yukon River
Marsh Lake to Schwatka Lake

FINAL REPORT

February 2010

Prepared By

Fuad Curi, P.Eng.
Senior Water Resource Engineer

Approved By

for Rick Carson, P.Eng.
Manager, Water Resources Services

KGS Group
Winnipeg, Manitoba

Kontzamanis | Graumann | Smith | MacMillan | Inc.

KGS GROUP
CONSULTING ENGINEERS

3rd Floor
865 Waverley Street
Winnipeg,
Manitoba
R3T 5P4
204.896.1209
fax: 204.896.0754
www.kgsgroup.com

February 5, 2010

File No. 09-1404-07

Yukon Energy Corporation
#2 Miles Canyon Road
Whitehorse, Yukon Territory
Y1A 6S7

ATTENTION: Mr. Ron Gee, P. Eng.

RE: Hydraulic Modelling of Yukon River
Marsh Lake to Schwatka Lake
Final Report

Dear Mr. Gee,

Please find enclosed an electronic copy (PDF format) of the Final Report of the Hydraulic Modelling of Yukon River - Marsh Lake to Schwatka Lake.

We appreciate the opportunity of providing you with our services. If you have any questions regarding this report please contact the undersigned.

Yours truly,

for

Rick W. Carson, P.Eng.
Manager, Water Resources Services

DW/jr
Enclosed

EXECUTIVE SUMMARY

An analysis of the hydraulic conditions of the Yukon River during the 2007 flood was conducted to investigate the effects of possible measures intended to reduce the peak water levels experienced in Marsh Lake during the event.

For the analysis, a numerical model of the river was developed based on the available bathymetric data. It was applied to examine the response of Marsh Lake to a drawdown of Schwatka Lake, and to a hypothetical condition that would have occurred in 2007 if the Lewes Dam had not been in place.

The results show that a drawdown of Schwatka Lake from the normal supply level (El. 653.19 m) to the low supply level (El. 652.272 m) could have reduced the water levels at Marsh Lake up to 10.5 cm in an event such as that of 2007.

It was identified that the 10-km reach upstream of the Whitehorse Rapids Dam has several features that act as hydraulic controls to the Yukon River water levels. The major hydraulic controls are Miles Canyon for flows higher than approximately 400 m^3/s, and the rapids located 5.3 km upstream of Miles Canyon, near the area known as McCrae, for flows lower than approximately 400 m^3/s. For a given flow rate, these controls reduce the effect of variations in downstream water levels at Schwatka Lake.

The hypothetical case in which the Lewes Dam was not included in the model reduced the computed 2007 peak water level on Marsh Lake by 14.4 cm from the base case. The removal of the sill at that site (but retaining Lewes Dam Structure) resulted in a reduction of the peak water level at Marsh Lake of 3.8 cm, while the opening of the boat lock (retaining the present configuration at the site) resulted in a 3.5 cm reduction of the Marsh Lake peak level.

The effects of a hypothetical drawdown of Marsh Lake, up to 0.32 m below minimum licensed water elevation, prior to the start of the 2007 flood, were found insignificant in reducing the water levels in Marsh Lake at the peak of the flood.

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1.0 INTRODUCTION

This hydraulic study encompasses a portion of the Yukon River from Marsh Lake to the Whitehorse Rapids Dam. This stretch of river is approximately 50 km long and flows to the northwest towards the City of Whitehorse.

The water level of the downstream reservoir, Schwatka Lake, is regulated at the Whitehorse Rapids Dam and ranges from a full supply level of El. 653.339 m to a low supply level of El. 652.272 m, with a normal operating level of El. 653.19 m. Approximately 3.5 km upstream of the Whitehorse Rapids Generating Station there is a narrow water passage known as Miles Canyon where the riverbed rises abruptly and the river is less than 30 m wide. A study by Acres International in 2005 concluded that at high flows, the flow through Miles Canyon would be near critical[1], effectively acting as a control for upstream levels that would be independent of the water levels at Schwatka Lake. Approximately 9 km upstream from Whitehorse Rapids Generating Station, near the area know as McCrae, a set of rapids provides an additional hydraulic control on upstream river levels. About 30 km upstream of the Whitehorse Rapids Generating Station there is a gated control structure, known as the Lewes Dam, which regulates the winter flows downstream of Marsh Lake.

The purpose of this study was to evaluate the effects of the Schwatka Lake levels and the Lewes Dam on the water levels at Marsh Lake.

Simulations of Yukon River flows were conducted using the one-dimensional computer model Hydrologic Engineering Center – River Analysis System (HEC-RAS) developed by the US Army Corps of Engineers. The model was prepared with topographic data collected in 1995 by Lamerton Associates and with drawings of the Lewes Dam. Additional data was collected in 2008 after a preliminary study by KGS Group. The model was calibrated to a water surface profile surveyed by Underhill Geomatics Ltd. on July 8, 2005 and confirmed by comparing the computed water levels on Marsh Lake with recorded levels for the summer of 2007.

1 “Critical flow” is an engineering term that defines the point at which further lowering of a water level downstream of a constriction does not influence the water level upstream of that constriction.

2.0 PRELIMINARY STUDIES

In 2008 KGS Group completed a hydraulic model of the Yukon River, simulated five different theoretical operating conditions, and investigated the effects that these conditions would have on the water levels on Marsh Lake. During the early part of this study, some gaps were found in the data that had been provided by YEC. Since that time, YEC commissioned additional surveys of the river to supplement the original data, and the findings from this are reported herein.

3.0 DATA SOURCES

Data for this study was provided by the Yukon Energy Corporation and consisted of:

- 40 cross sections of the Yukon River surveyed by Lamerton Associates in 1995. A text file with the cross sectional data, location maps and drawings of the cross sections.
- AutoCAD drawing of a water surface profile of the river reach, surveyed by Underhill Geomatics Ltd. on July 8, 2005. During the 2008 study, this water surface profile was found to require corrections that have now been properly applied.
- Drawings and operating procedures of Lewes Dam. This included drawings of both the new dam as well as the previous sill that was left in place.
- Observations of the river by KGS Group staff during the 2006-2007 winter and by Underhill Geomatics during the 2007-2008 winter.
- 17 Additional cross sections of the river, surveyed in October 2008, particularly in the areas of Miles Canyon, McCrae Rapids, and between Lewes Dam and Marsh Lake.
- Water levels of Marsh Lake recorded by the Water Survey Of Canada Gauge # 09AB004 and flows at Whitehorse Rapids Dam recorded by Gauge # 09AB001.

KGS Group's general knowledge of the Yukon River from previous projects was also used for the preparation and validation of the river model, as well as visual images from Google Earth.

4.0 NUMERICAL MODEL PREPARATION AND VALIDATION

The HEC-RAS numerical model was prepared with the basic geometric data from the 1995 survey of the river as well as cross sections from the October 2008 survey, and the available drawings of Lewes Dam.

The water level profile measured by Underhill Geomatics Ltd. in 2005 showed a discontinuity of about 30cm, located near Station 9000 m (5.3 km upstream of Miles Canyon, near the area of McCrae). A set of rapids was thought to exist at this location, which was not properly represented in the October 2008 cross section survey and the corresponding backwater model. A crew dispatched by YEC in December 2007, confirmed the presence of open water at that site during the winter 2007-2008. This indicated that rapids do exist at this location. The model was adjusted by including a rise in the riverbed that allowed representation of these rapids and the water levels measured in 2005.

New surveys carried out in 2008 included this particular location. The intention was to identify the location of the rapids and confirm the geometry of the river in that area. The updated model with the new cross sections still did not properly represent the rapids. Recognizing the information (river profile, photos, and anecdotes) that supports the presence of these rapids, the model was adjusted accordingly by including a raised riverbed at that location to represent the rapids.

The model of the river was calibrated using the water surface profile surveyed on July 8, 2005 and validated using the available 2007 data. The latter included only two locations for water surface elevation: Marsh and Schwatka lakes for a variety of flows. The estimated flow for the date of the water surface profile survey in 2005 was 435 m^3/s. This was the value used for the calibration of the model. Figure 1 shows the surveyed water surface elevations compared to the model calibration results.

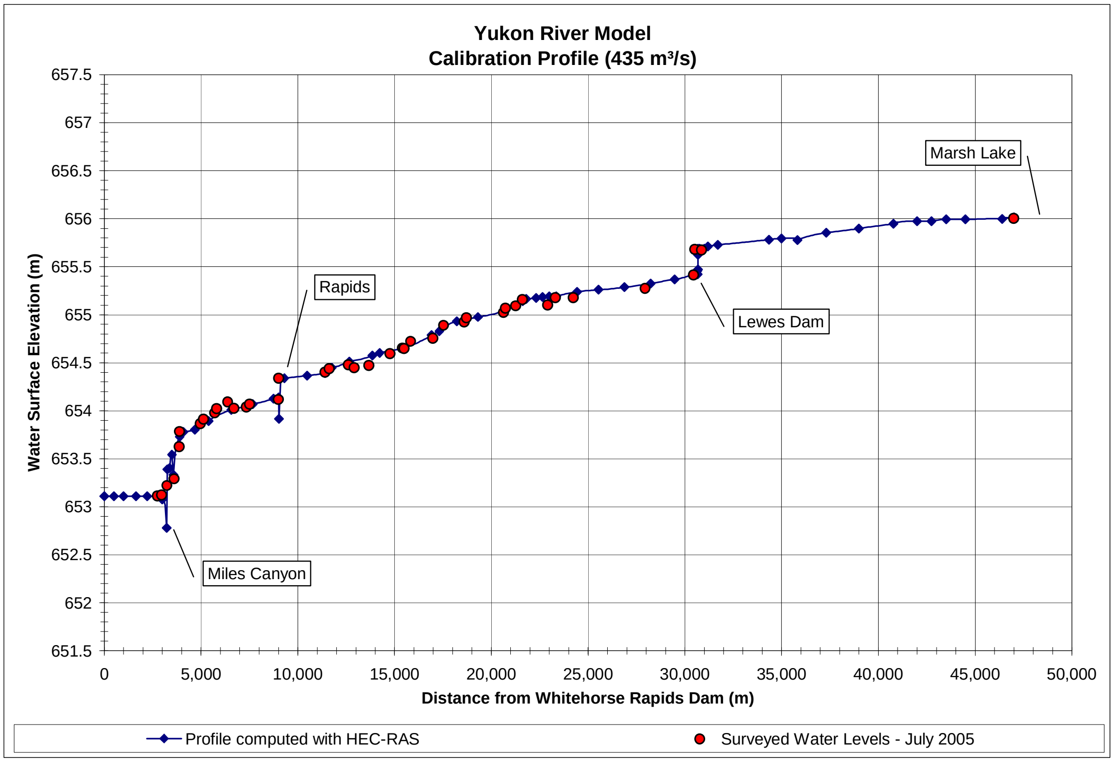

Figure 1 – Yukon River Model Calibration

The calibration was further tested by simulation of the historical conditions during the summer of 2007 and by comparing the model results with the recorded water levels. Table 1 shows a comparison of recorded water levels on Marsh Lake with those simulated by the model.

Table 1 - Water Surface Elevations at Marsh Lake – Computed vs. Actual

Date	Recorded Yukon River Flows (m^3/s)	Marsh Lake Water Levels (m)		Difference Between Actual and Modeled Levels (m)
		Actual	Modeled	
4-Jun-07	203.74	654.354	654.396	0.042
12-Jun-07	302.12	655.030	655.122	0.092
19-Jun-07	399.24	655.645	655.755	0.110
2-Jul-07	503.02	656.412	656.476	0.064
21-Jul-07	606.29	657.080	656.998	-0.082
25-Jul-07	632.06	657.210	657.155	-0.055
12-Aug-07(PEAK)	644.85	657.343	657.235	-0.108
5-Sep-07	599.82	657.128	656.993	-0.135
30-Sep-07	528.19	656.623	656.559	-0.064

The differences between actual and computed values shown in Table 1 are typical of this type of model and are considered acceptable. The numerical model is believed to be capable of reliably investigating the effects of changes in operation strategy.

The average flow for the dates corresponding to the October 2008 survey, as recorded by the Water Survey of Canada gauge at Whitehorse Rapids Dam, was simulated in the model. The computed water surface profile was then compared to the water levels recorded during the survey. This comparison is shown in Figure 2 below. Computed water levels in portions of the river do not match this survey as closely as the 2005 water surface profile.

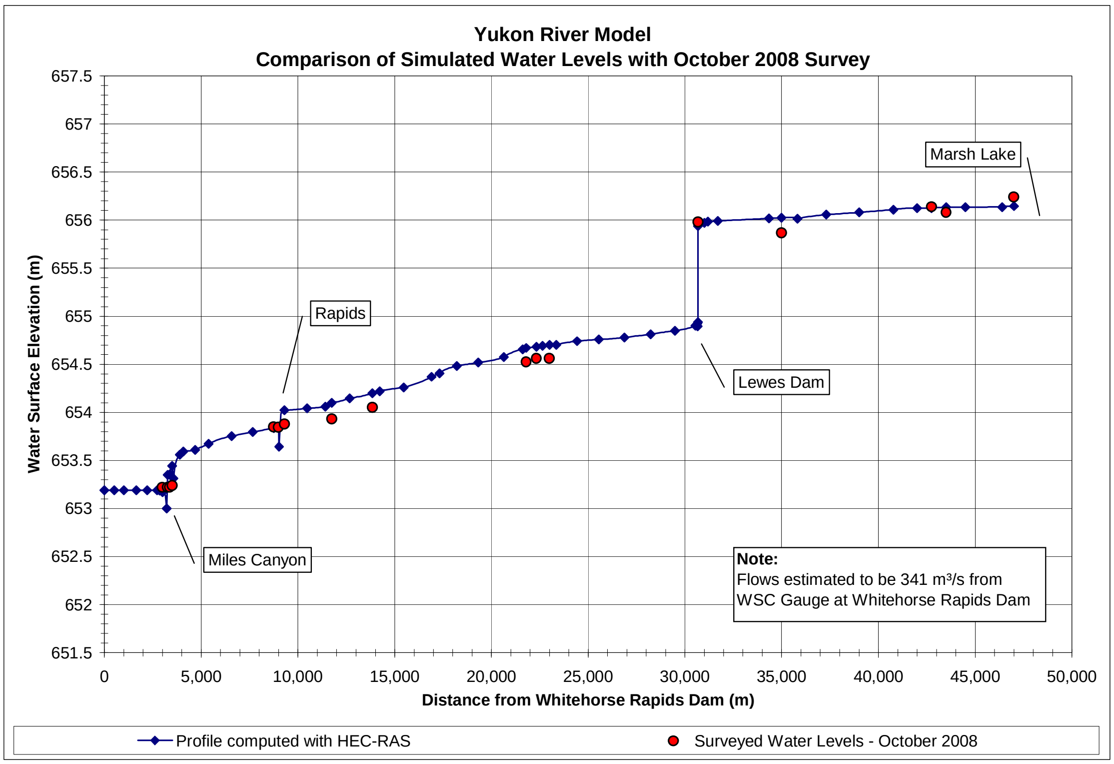

Figure 2 – Comparison of Simulated Water Levels with October 2008 Survey

5.0 SIMULATIONS AND ANALYSIS OF SCENARIOS

Five scenarios were simulated with the calibrated model representing the flows occurring during 2007 with the following conditions:

1. River under present conditions with Schwatka Lake at the normal operation level (653.19 m)
2. River under present conditions with Schwatka Lake at the low supply level (652.272 m)
3. River without the Lewes Dam Control Structure, with Schwatka Lake at normal operation level (653.19 m)
4. Sill at Lewes dam removed, with Schwatka Lake at normal operation level (653.19 m)
5. River under present conditions with Schwatka Lake at normal operation level (653.19 m), boat lock at Lewes Dam opened.

Scenario 1 is the "base case" against which all other scenarios are compared, in a relative sense. Scenario 1 differs slightly from the actual conditions that occurred in 2007 (see slight differences shown in Table 1). However, the underlying reasons for these slight deviations are also embedded in the simulations for all the scenarios. As a result, the differences between Scenarios 2 to 5 and Scenario 1 are believed to be indicative of differences that would occur from the actual observed conditions in 2007.

The overall implications of removing the sill at Lewes Dam (Scenario 4) have not been rigorously assessed. This scenario is a hypothetical case, presented only to show the approximate effects that it would have on the water levels on Marsh Lake. Structural or other considerations not included in this study may render this hypothesis unsuitable.

For the simulation of these scenarios with HEC-RAS, boundary conditions were required at the upstream and downstream ends of the model. The downstream boundary conditions of the model for each scenario correspond to the specified Schwatka Lake levels.

The upstream boundary conditions were the outflows from Marsh Lake, calculated for each case. The calculation of these flows was based on the inflows-available-for-outflow[2], derived from the records of the summer of 2007, routed through Marsh Lake. The period of record used in this study spanned from June 2, 2007 to Sept 30, 2007. The inflows-available-for-outflow were obtained from

2 "Inflow-available-for-outflow" is inflow to the lake computed from known outflows and lake levels. It implicitly includes the effects of evaporation and precipitation.

the historical Yukon River Flows downstream of Marsh Lake, the recorded Marsh Lake Levels, and a stage-storage curve developed for Marsh Lake.

For regular flows under normal conditions Marsh Lake, Tagish Lake, and Bennett Lakes are effectively one large pool that rise and fall nearly in unison. Together they have a surface area of close to 550 km², as determined in the Southern Lakes Study by Northwest Hydraulic Consultants. However, under flood conditions similar to the flood event during the summer of 2007, the lakes act separately due to flow restrictions at their outlets under the high flows involved. Therefore, a constant Marsh Lake surface area of 100 km² (corresponding to Marsh Lake only) was assumed.

The Yukon River flows and Marsh Lake levels for each of the scenarios described above were obtained by a combination of HEC-RAS model calculations and level pool flood routing through Marsh Lake. Stage-discharge rating curves for the Marsh Lake outlet were developed separately for each scenario, using the HEC-RAS model of each condition. These rating curves were applied in the level pool flood routing of Marsh Lake inflows-available-for-outflow to obtain adjusted outflows from Marsh Lake for each scenario. The adjusted outflows were then used for a new run of the HEC-RAS models to calculate the hydraulic profiles of the river corresponding to the study period. The starting conditions for the level pool flood routing through Marsh Lake correspond to the actual water level on June 2, 2007(El. 654.271 m).

6.0 PRE-EMPTIVE DRAWDOWN OF MARSH LAKE

Additional calculations were made to address the effects of a hypothetical prior drawdown of Marsh Lake in advance of a flood. The analysis consisted of performing a level pool flood routing of the inflows-available-for-outflow for Marsh Lake, assuming a lower level of the lake at the start of the flood, on June 2, 2007. The adopted low level was El. 653.476 m, which is 0.32 m below the low supply level defined in YEC's water license for Marsh Lake. This low level corresponds to the minimum reported for Marsh Lake since Yukon Energy has been operating the Yukon River system, and occurred in 1966.

The resulting Marsh Lake outflows and water levels obtained with the adapted low level were compared to those calculated based on the actual water levels for June 2, 2007 (El. 654.271 m). The purpose of this calculation is to examine whether these hypothetical conditions would result in any sizeable reduction of the Marsh Lake levels at the peak of the flood. It does not imply any suggestions for changing the limits specified in YEC's license; neither does it constitute an exhaustive evaluation of the implications that these hypothetical conditions would have in the overall operation of the river system.

The constant Marsh Lake surface area of 100 km^2 that was determined in the Southern Lakes Study by Northwest Hydraulic Consultants was used in this analysis.

7.0 RESULTS

7.1 GENERAL

The results of the analyses are presented in terms of difference in water levels between actual conditions and hypothetical scenarios. The numerical model is not generally capable of predicting the water surface profile within an absolute accuracy of 5 to 10 cm. However, differences between scenarios, where only one aspect of the model is varied (for example the level of Schwatka Lake), are more accurate and meaningful. The differences are reported to fractions of a centimetre and represent the numerical results of the models.

7.2 RESULTS OF THE HEC-RAS SIMULATIONS

Table 2 shows the resulting water levels at Marsh Lake for each of the simulated scenarios. Table 3 shows the difference in Marsh Lake levels for all scenarios with respect to Scenario 1, for the 2007 flood.

Figures 3 to 7 show water surface profiles for the Yukon River for a range of flows and for Scenarios 1 to 3. The profiles extend from Marsh Lake to the Whitehorse Rapids Dam and correspond to flows from about 200 m^3/s (Figure 3) to about 640 m^3/s (Figure 7). The profiles for Scenarios 4 and 5 are the same as those of Scenario 1 from the Lewes Dam Site to Schwatka Lake. Figure 8 shows the effect of various hypothetical configurations at the Lewes Dam site on the water levels upstream.

The results show that the river features several hydraulic controls in the 10 km upstream of the Whitehorse Rapids Dam. These include Miles Canyon and the rapids located 5.3 km upstream of Miles Canyon, near the area of McCrae. Upstream of this reach, the influence of Schwatka Lake levels is minimal, so the water surface profiles shown in Figures 3 to 7 are very similar for locations upstream of this reach.

It can be seen in Figures 6, 7 and 8 that for very high flows, the water levels on Marsh Lake are slightly higher for Scenario 1 than for all other scenarios. Figure 9 shows Marsh Lake levels for each of the scenarios during the simulated period. Figure 10 is similar to Figure 9, but shows only the levels near the time of the peak of the flood. Figure 11 shows the differences in Marsh Lake levels, obtained from the HEC-RAS simulations, for Scenarios 2 to 5, with respect to Scenario 1.

The effects that drawing down the level of Schwatka Lake prior to the flood would have on the Marsh Lake levels are shown in Table 3 and Figure 10. With respect to Schwatka Lake at the normal operating level, this effect would be 10.5 cm for Schwatka at low supply level.

Figures 3 to 7 show that there are sizeable head losses in the reach from Marsh Lake to 10 km upstream of the Whitehorse Rapids Dam. For high flows, these losses are more than 1.5 metres, excluding the losses caused by the Lewes Dam and sill. These are a result of the limited conveyance of the Yukon River, and they further moderate the differences in the water level profiles for the various scenarios analysed.

The effects of the various alternatives investigated for the Lewes Dam site are shown in Figure 9 and in Tables 2 and 3. The maximum increase in Marsh Lake water levels caused by the Lewes Dam, for the 2007 flood, corresponds to the difference between Scenarios 1 and 3, and amounts to approximately 14.4 cm. For the conditions of the summer of 2007, the removal of the sill at that site would have reduced the water level in Marsh Lake by 3.8 cm. Opening the boat lock would have reduced the water level in Marsh Lake by 3.5 cm.

Table 2 – Water Surface Elevations for Marsh Lake – Simulations

Date	Calculated Marsh Lake Water Surface Elevations (m)				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
4-Jun-07	654.398	654.387	654.384	654.394	654.395
12-Jun-07	655.125	655.100	655.066	655.109	655.108
19-Jun-07	655.760	655.733	655.673	655.737	655.736
2-Jul-07	656.490	656.430	656.372	656.461	656.461
21-Jul-07	657.017	656.925	656.884	656.984	656.983
25-Jul-07	657.175	657.078	657.039	657.141	657.142
12-Aug-07	657.261	657.156	657.118	657.224	657.226
5-Sep-07	657.017	656.912	656.877	656.980	656.984
30-Sep-07	656.579	656.488	656.446	656.547	656.544

Notes: The peak of the flood ranges for all scenarios occurs on August 12.

Table 3 – Difference in Marsh Lake Levels at the peak of the 2007 Flood

Difference in Calculated Marsh Lake Water Surface Elevations With Respect to Scenario 1 (m)			
Scenario 2	Scenario 3	Scenario 4	Scenario 5
0.105	0.144	0.038	0.035

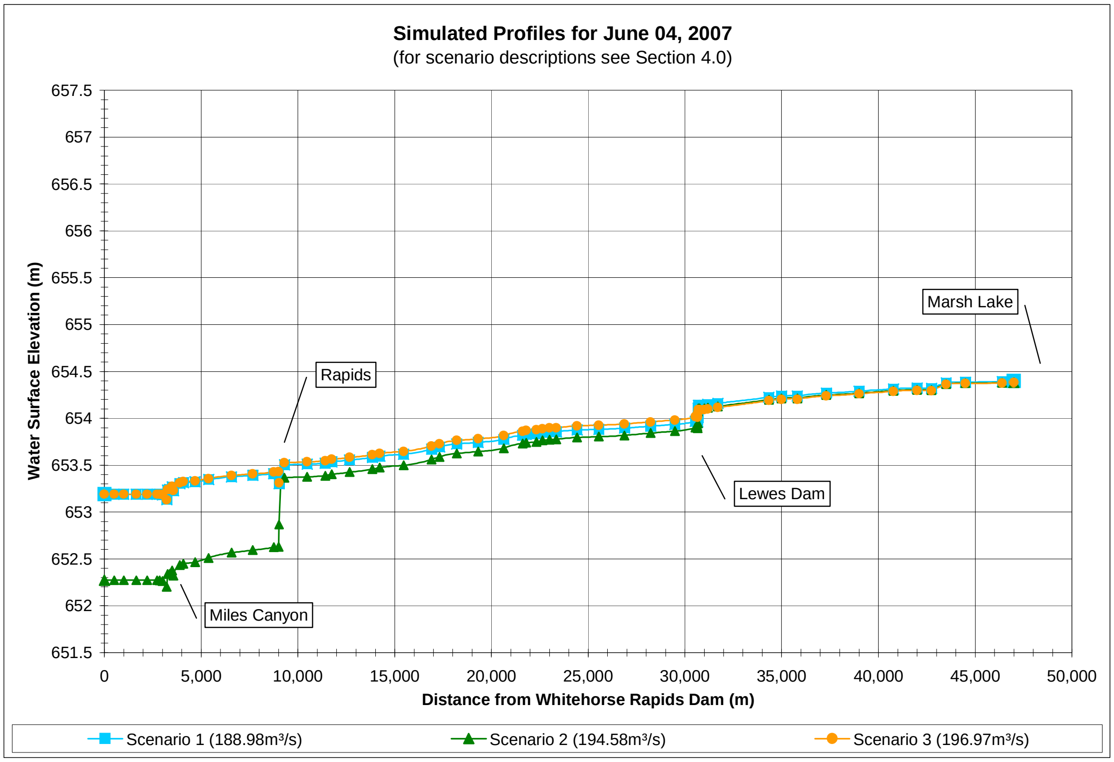

Figure 3 – Simulated Peak Water Surface Profiles for June 4, 2007

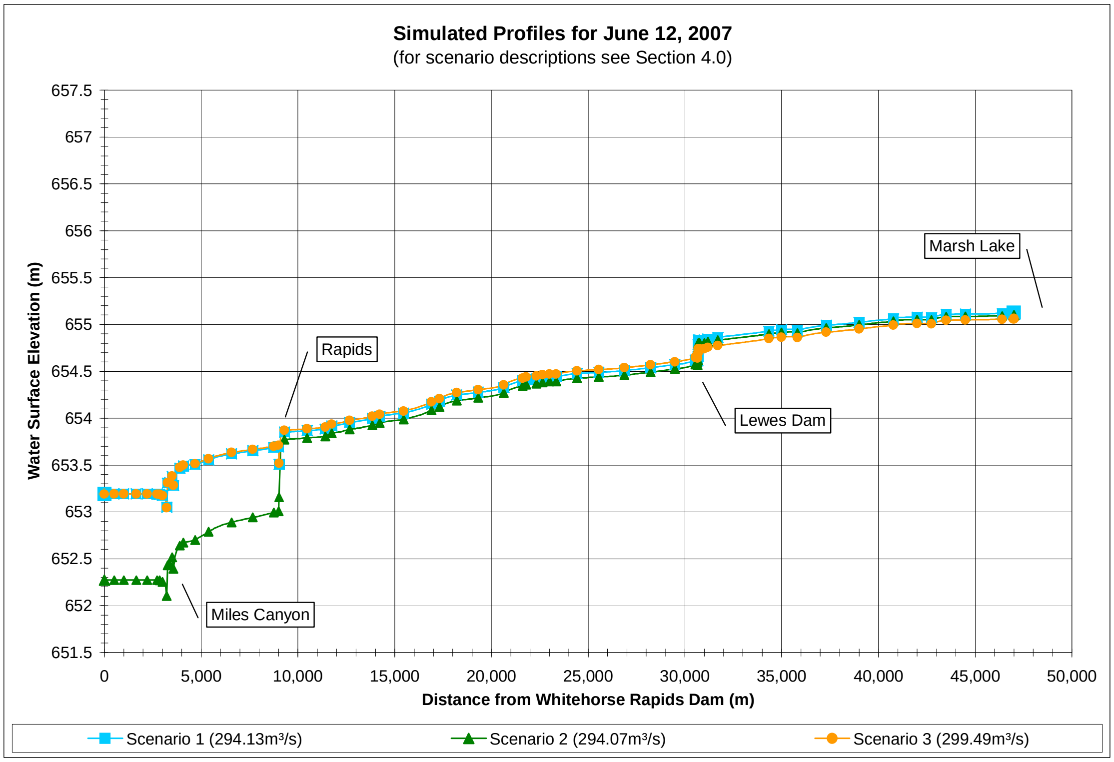

Figure 4 – Simulated Peak Water Surface Profiles for June 12, 2007

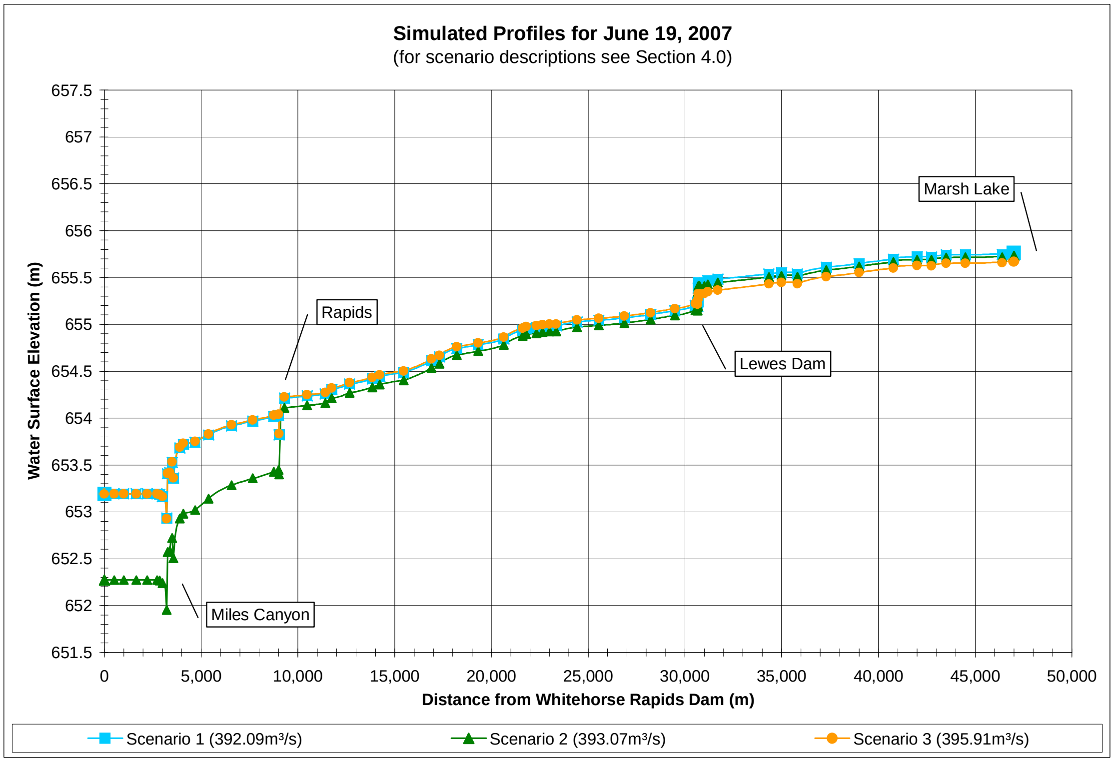

Figure 5 – Simulated Peak Water Surface Profiles for June 19, 2007

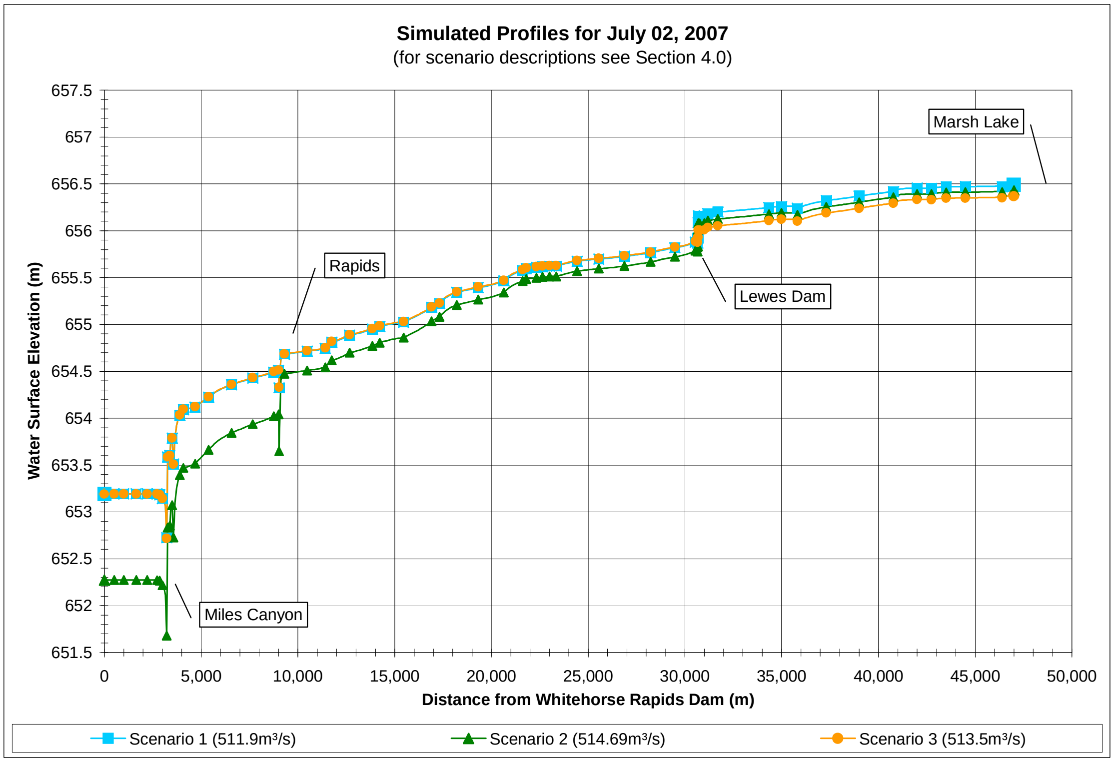

Figure 6 – Simulated Peak Water Surface Profiles for July 2, 2007

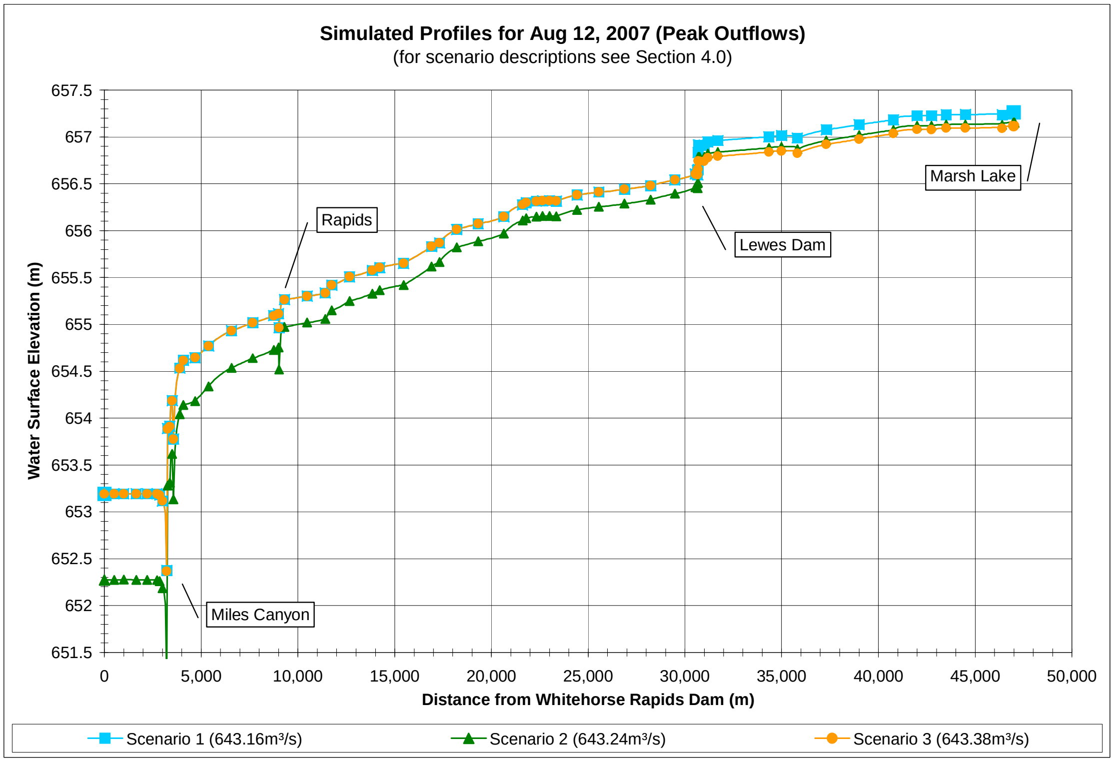

Figure 7 – Simulated Peak Outflows and Water Levels for 2007 Event

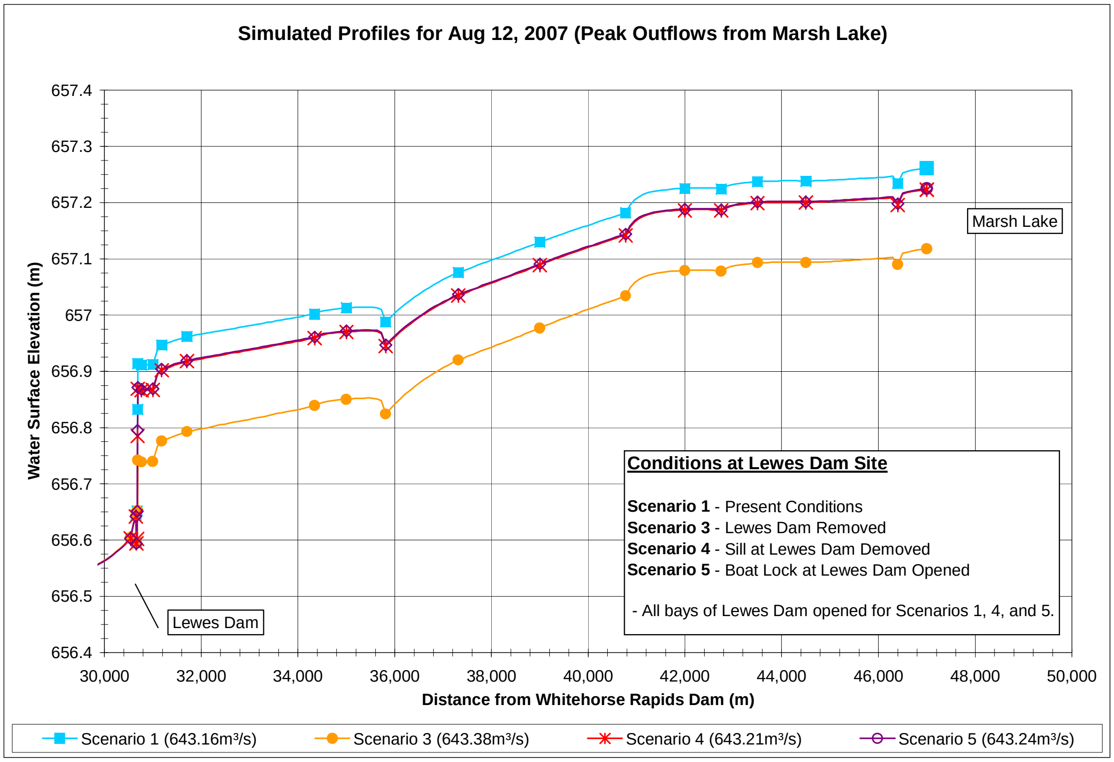

Figure 8 – Water Surface Profiles for Hypothetical Scenarios at the Lewes Dam

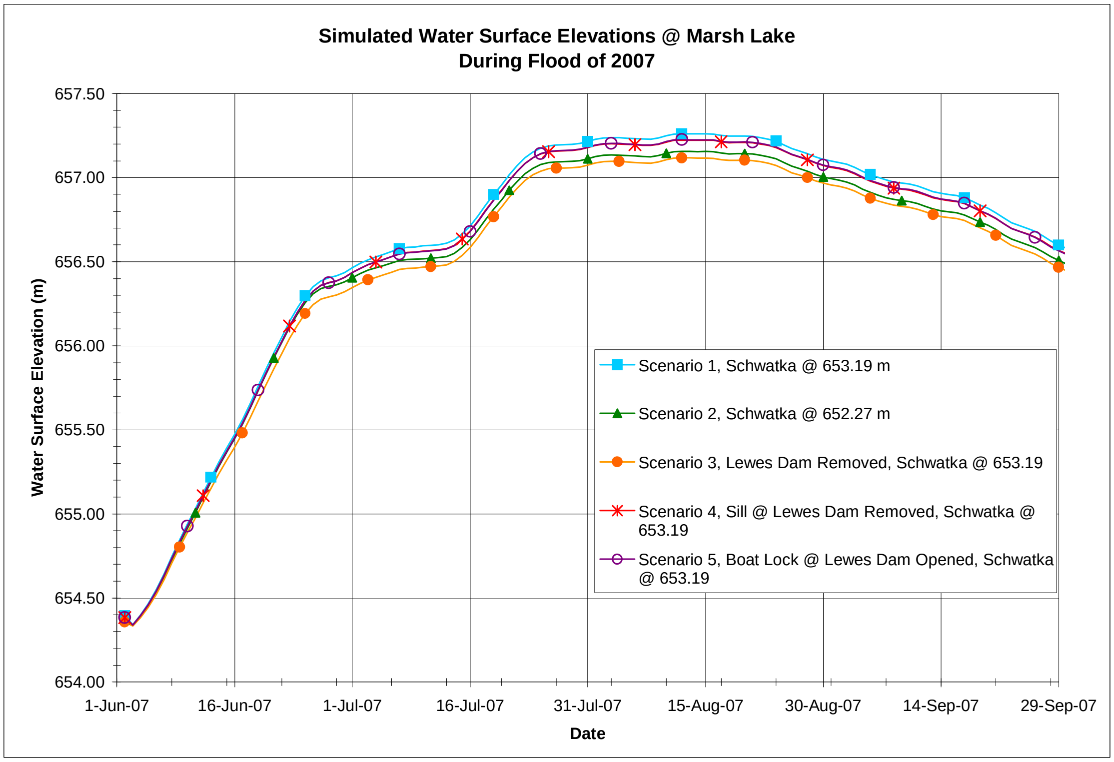

Figure 9 – Estimated Water Surface Elevations Marsh Lake

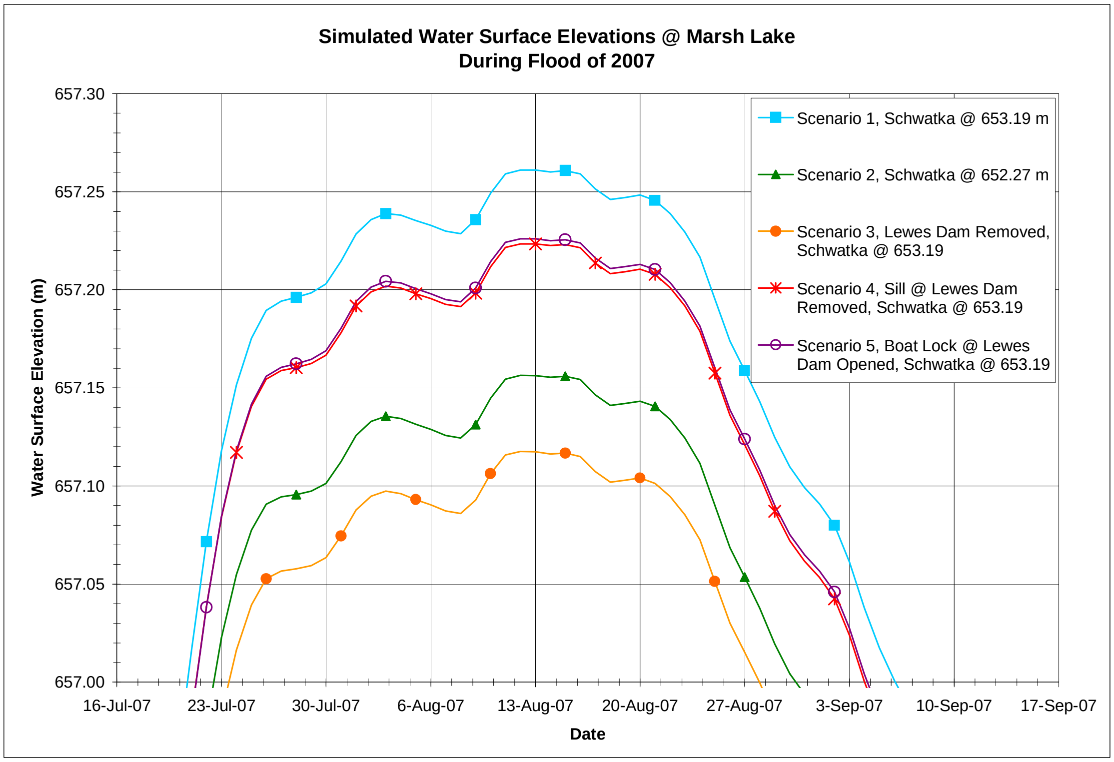

Figure 10 – Marsh Lake Water Surface Elevations at the Peak of the Flood

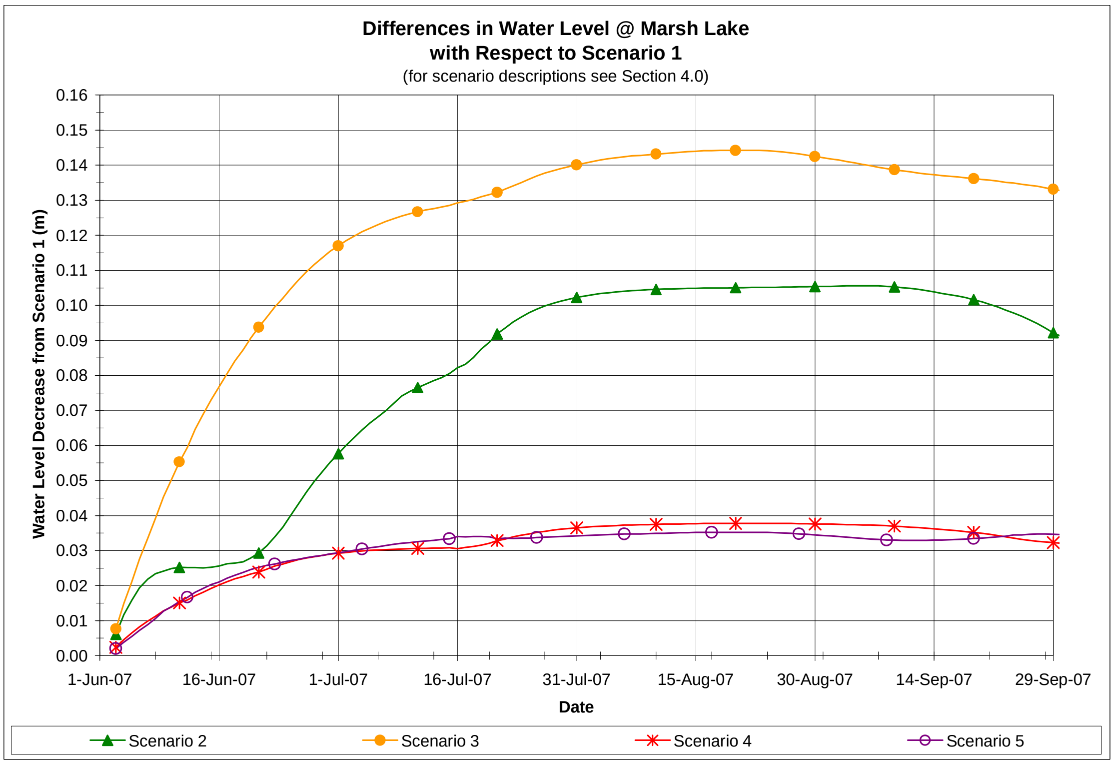

Figure 11 – Difference in Marsh Lake Levels Obtained from HEC-RAS Simulations (As compared to Scenario 1)

7.3 EFFECTS OF THE PRE-EMPTIVE DRAWDOWN OF MARSH LAKE

The effect of drawing down the Marsh Lake levels, to achieve a water level of El. 653.476 m on June 2, 2007, as opposed to the actual level of El. 654.271 m, was found insignificant. While the assumed drawdown level would have provided an additional 79.4 million cubic metres of storage, with respect to the actual level, the analysis showed that this additional storage would have been filled by early to mid-July, 2007. Subsequent water levels at Marsh Lake would have been virtually identical for the two cases, as shown in Figure 12.

This phenomenon is not uncommon and is related to the fact that at lower water levels, and barring any differences in outflow control, the outflow from the lake would always be less than at higher levels. Consequently, for equal inflows, the lower-starting-level condition results in a more rapid filling of the reservoir. At the peak of the flood, the initial difference in water levels would therefore be reduced and, typically becomes insignificant when the reservoir is relatively small with respect to the volume of the flood (as is the case of Marsh Lake where the flood volume is more than 10 times the lake storage).

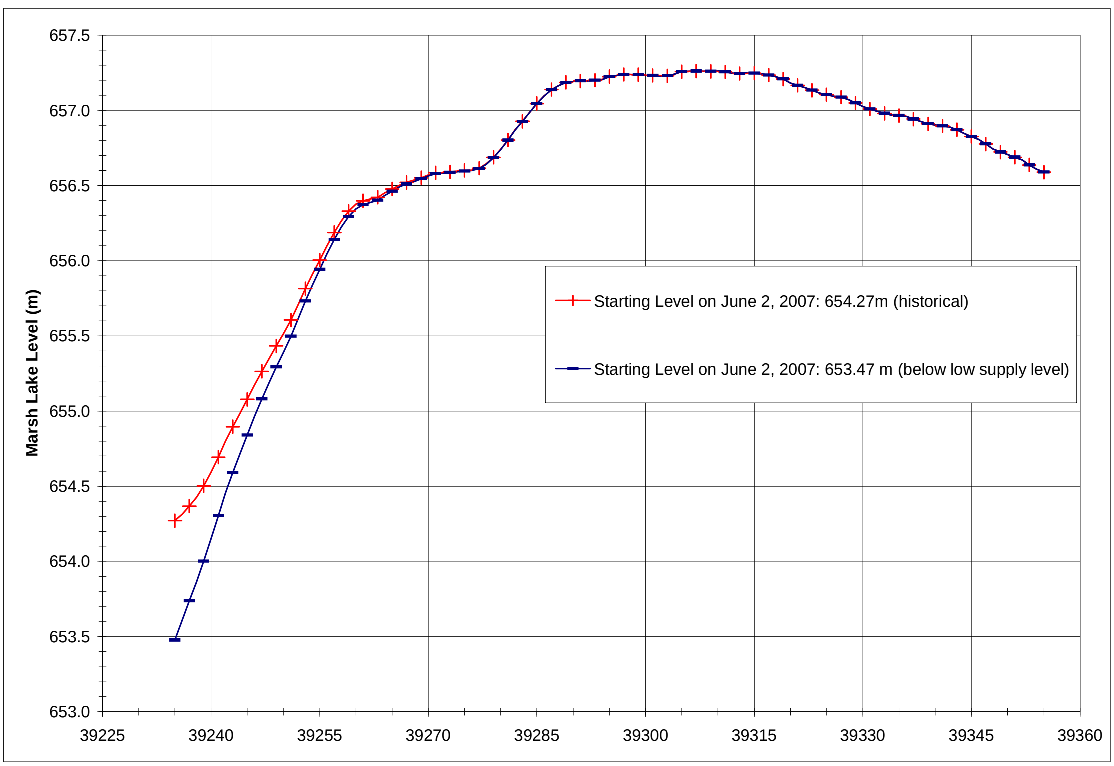

Figure 12 – Water Levels on Marsh Lake During the Summer of 2007
(Computed for Actual Conditions and for a Pre-Emptive Drawdown of Schwatka Lake)

8.0 CONCLUSIONS

The following conclusions result from the numerical simulation of Yukon River flows for the summer of 2007.

The hydraulic characteristics of the Yukon River, and in particular the 10 km reach upstream of the Whitehorse Rapids Dam, provide restrictions to the flow that cause sizeable head losses from Marsh Lake to Schwatka Lake.

Along the 10 km upstream of the Whitehorse Rapids Dam, the river features various hydraulic controls that substantially reduce the effect of Schwatka Lake level changes on the Marsh Lake water levels. The major hydraulic controls are Miles Canyon, in particular for flows greater than 400 m^3/s, and the rapids located 5.3 km upstream of Miles Canyon for flows lower than 400 m^3/s.

The effect on Marsh Lake levels of drawing down Schwatka Lake, from the normal operation level of 653.19 m to the low supply level of 652.27, would have been a reduction of approximately 10.5 cm at the time of the peak of the 2007 flood. This corresponds to a flow rate of about 640 m^3/s (2007 peak flow).

If the Lewes Dam had not been constructed (neither the sill nor the new structure), it has been estimated that the peak water level on Marsh Lake in 2007 would have been approximately 14.4 cm lower than what actually occurred. If only the new structure had existed and the old sill had been removed, the peak level on Marsh Lake was estimated to be 3.8 cm lower than what actually occurred. If the dam had existed in 2007 (both new structure and old sill downstream), but the boat lock on the right bank had been open (it was closed in the actual event of 2007), the peak water level on Marsh Lake was estimated to be 3.5 cm lower than what actually occurred.

A pre-emptive drawdown of Marsh Lake, to a level 0.32 m below the licensed low supply level, prior to an event similar to the 2007 flood, was found to have insignificant effects on the water level of the lake at the peak of the flood.