Detailed Report on the Modeling of the Proposed Changes at the Holme-Pierrepont National Watersports Center.

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Introduction

Holme-Pierrepont Whitewater Channel (HPP) has a long and storied history as the flagship venue for the British Canoe Union. Since its creation in 1986 this park has served as the national training center for the highly successful British Whitewater junior, national, and Olympic teams. It has also served as a recreational and rafting attraction and has hosted numerous national and international level whitewater competitions in a variety of differing events including both slalom and freestyle. As time has passed the channel, which was once state-of-the-art, has begun to suffer in utility as newer and more advanced and efficient channels are constructed around the world and as the boats used and activities pursued have also evolved.

There has been some effort at HPP to upgrade the existing channel through the use of omniflots in limited areas of the course. These moveable obstacles allow the channel operators to both modify and tune the park. The Omniflot obstacles are also currently used in several channels around the world and the implementation of these obstacles into the HPP channel affords British paddlers the opportunity to better prepare for competition on these other channels.

The most current effort at HPP is tasked with further enhancing the existing channel. It has been noted in public meetings, however, that there are parts of the existing channel system that stakeholders wish to preserve precisely in their current configuration and flow regime. The objective of the designers in this effort, therefore, is to create improvements in selected areas of the channel system while preserving areas that are currently valued by the various user groups. It is to this end that this study has been commissioned.

This study summarizes a computer flow modeling analysis that compares the existing HPP Whitewater Channel, in its most current configuration, with the proposed changes to this channel. The flow model outputs information with regards to expected average flow velocities, water surface elevations and other pertinent data and can be used to compare before and after effects at selected cross sections with differing boundary conditions (i.e.—the software allows for comparison of flow characteristics in sections that are to be preserved when placed in the existing channel and when placed in the proposed channel following improvements). The purpose of this investigation is to determine how the proposed changes will affect the course in areas that are intended to be modified and what effect the changes will have on sections of the course that are intended to be preserved in their current incarnation. The general objective of the design team is to create improvements in selected sections while having zero effect on sections of the course that are intended to be improved.

Methodology and Calibration

In order to evaluate the differences between the existing channel system and the proposed channel system a Baseline model was created using HEC-RAS. The existing model was created using both as-built and more recently surveyed points (used for the purposes of calibration) to create over a hundred cross sections within the selected reach. The model consists of a baseline geometry garnered from the actual concrete bed of the channel.

In this model the channel system is modeled as a single channel in the reach that extends from the Head gate to the location of the Muncher. At this point the channel divides with the majority of the flow staying in the main channel and a small amount of flow passing through the first recirculating channel (the “upper loop”). The channels join at the base of the first island into a single channel but then are subsequently divided at the downstream end of this pool into the main channel and the second recirculating channel (the lower loop). These channels join just above the bottom stopper. Boundary conditions were set within the software based on known water surface elevations at the upstream end and assumed water surface elevations at the downstream end (the downstream water surface elevation varies). Flow into the recirculation channels was calibrated, iteratively, until the water surface elevations at the upstream and downstream ends approximately matched those seen in the main channel. This configuration is shown in Figure 1 below[1]:

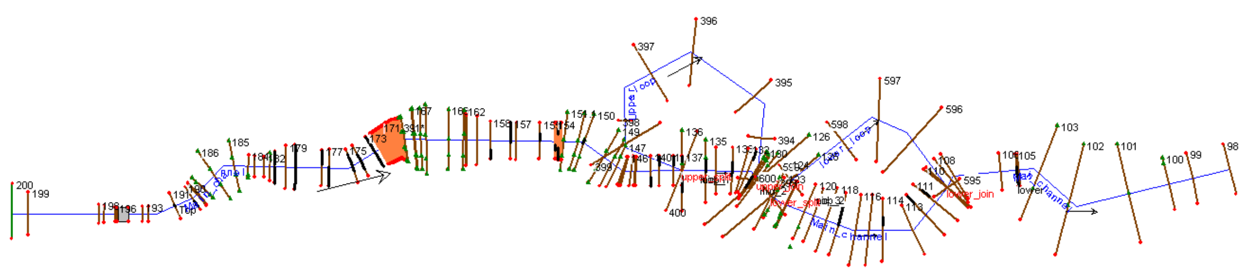

Figure 1. The modeled configuration of the HPP Channel.

[1] Note that the plan view of the geometry shown for the model is for illustrative purposes only. Calculations are made independent of the geometry sketched in this illustration.

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Figure 1, shown above, illustrates the location and configuration of the selected cross sections. In some cases—cases in which the flow character changed rapidly in a short distance, the software was used to interpolate additional cross sections. These cross sections are shown above in orange and allowed for a more accurate approximation of the two major hydraulic jumps. Higher resolution in these areas also helps the model to correctly resolve to the correct water surface elevation. Obstacles such as concrete blocks and omniflots were modeled within the software as obstacles placed on top of the concrete surface. The model was further refined to include ineffective flow areas in the large eddies and pools located throughout the course. An example cross-section taken at a familiar location—one that includes the Muncher— is shown in Figure 2 and illustrates the manner in which the channel was modeled.

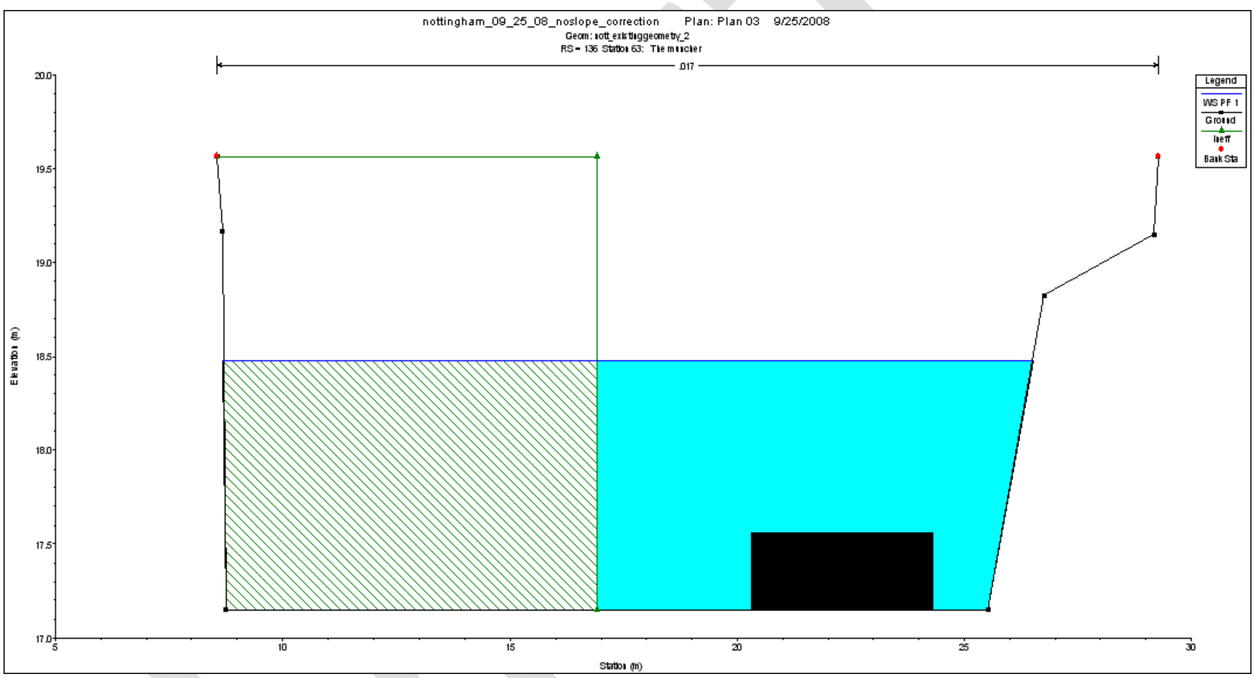

Figure 2. A section at the Muncher showing the projection of the obstacle that creates the Muncher as well as the ineffective flow area that forms the eddy on river left at this location.

The preliminary baseline model was then compared to surveyed water surface elevations (WSE) within the channel in order to calibrate the model. The calibration required several steps as the flow in the HPP channel on the day of the survey heretofore assumed was also a variable in the study.

At its upstream end, the flow into the channel is controlled by a Bear Gate type head gate. This was modeled in HEC RAS as an inline structure similar to a hardened dam. Elevation data for the Gate was measured on the same day and time that the WSEs were measured. An iterative process—guided by

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the Weir Equation—was used within HEC RAS in order to determine the assumed flow in the channel. A small amount of water was assumed to be leaking through the gate in this process. The total flow in the channel at the headgates was found to be approximately 17.5 cumecs using this method.

In order to confirm this finding, which seemed unlikely given the stated capacity of the channel, a check was done of water surface elevations upstream of two key critical flow sections. Critical flow sections, for the uninitiated, are sections in which the flow quantity, in cumecs, can be determined through the knowledge of the geometry of the channel and the water surface elevation (and, of course, knowledge that the flow is, in fact, critical). There are two sections that were identified through knowledge of the course where river-wide critical flows occur. The first is at the drop structure known as "Jaws" and the second is at the drop that falls into the Looping Pool. Comparisons of the surveyed WSE and WSE predicted by the HEC-RAS model at 17.5 cms agreed at both of these locations confirming the predicted flow of 17.5 cms. A quick check of the flow elevation at the existing gauge was found to agree with the WSE predicted by the model. This elevation is shown in Figure 3:

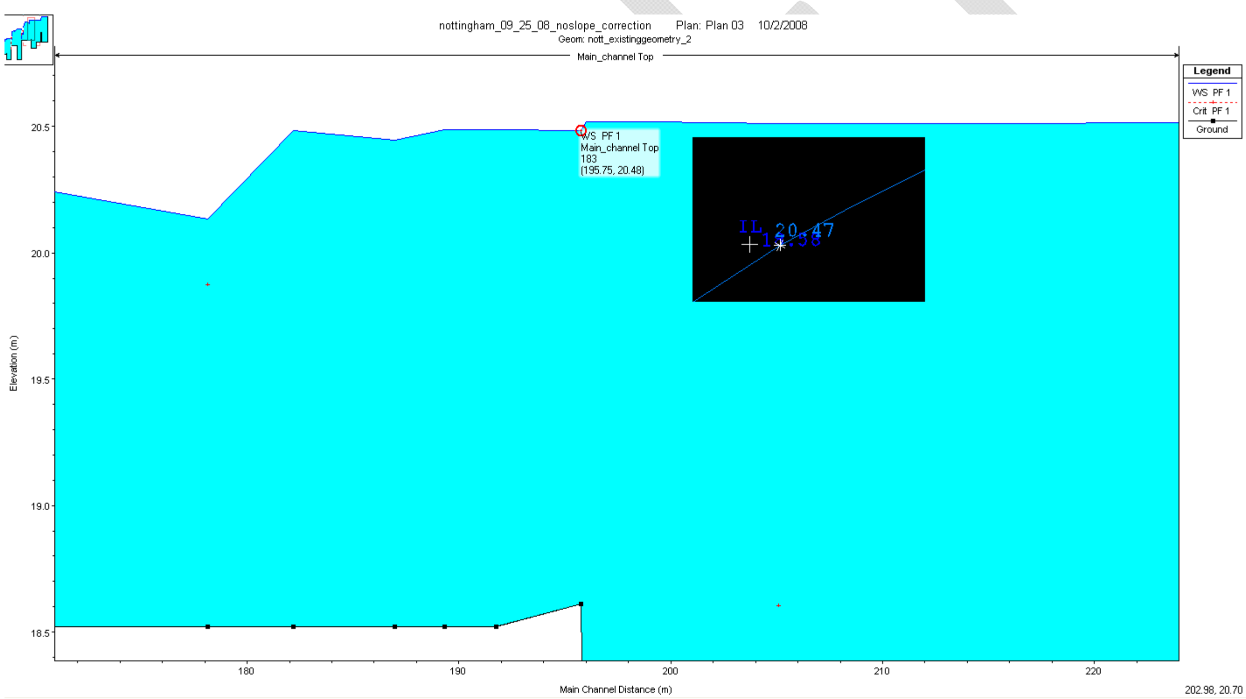

Figure 3. The water surface elevation at the location of the existing gauge shown as an output from the HEC-RAS model and, in the black insert, as surveyed on the day the flows were measured for calibration.

Figure 3 shows the water surface elevation at the existing gauge to be 20.48. The measured water surface elevation on that day was found to be 20.47. Based on these checks it was concluded that the

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flow in the channel is approximately 17.5 cumecs.

Water surface elevations throughout the model were then compared in order to establish the overall accuracy of the model. Verification of a model is often difficult as there are several sources of error in the measuring process and it is hard to differentiate between these sources and model error. Possible sources of error include:

- **Measurement of the water surface elevation:** Measurements are taken on the shore where, quite often, inertial effects cause the downstream end of the eddy to be higher in elevation than the upstream (when, in fact, the actual flows are slanted in the opposite direction). In many cases neither of these elevations corresponds to the average or center channel elevation. In other cases, such as when the river bends or when an obstacle is placed close to the wall the elevations on both sides of the river do not agree and are affected by local effects that cause them to differ from the average water surface elevation.

- **Survey Information:** The initial survey information is merely an interpolated model of the channel. This information is then read off at the selected cross section locations and then interpolated again when entered into the computer model. Each of these interpolations introduces error and leads to an "error band" of uncertainty within which model outputs are imprecise.

- **Location information:** In this comparison the closest points to the cross section are read for the purposes of determining water surface elevation. In some cases the cross sections were located some meters upstream or down.

- **Resolution of the model:** The model also interpolates a water surface elevation (in addition to the aforementioned geometry interpolations)whereas a field measurement is the actual water surface elevation and is therefore more resolute.

- **Other:** There are other, more minor sources, of error

A representative sample of elevations were compared to determine the error between the model and the actual surveyed cross sections. This sample includes all points that were determined to be reasonable when considered in the context of the limitations noted above (i.e. Not far from modeled cross-sections, not in areas in which inertial effects of the water would skew measured vs. averaged results, etc.) The first type of error checked was bias—which is to say the model was first checked to see if there was a global tendency within the model to represent elevations as too high, or too low. In the instance of bias once could conclude that either the base geometry, roughness, some of the energy coefficients, or the total flow of the channel were modeled incorrectly. To check this the two results were subtracted (to find the difference) and averaged . The average computed bias was found to be of -

.004 meters. Based on this result it was concluded that there is negligible bias in the model.

The second type of error checked was the random error within the model. This is a check of the width of the error band of uncertainty within the model. As an example, if the survey methods used on the channel had an accuracy of +/- 1 cm then one could conclude that it would be difficult to know the water surface elevations within +/- a centimeter. Given that this study—as all such studies do—has a wider band of error then some attempt must be made to characterize the total width of the error band. One such way to characterize the width of the error band is to simply calculate the standard deviation, which is a measure of the statistical dispersion of a data set, of the difference between the computed and measured values for the specified sample of points. If a data distribution is approximately normal then about 68% of the values are within 1 standard deviation of the mean. The standard deviation of the difference of the two results was found to be 5.8 cm with the greatest source of error found at the looping pool (where it can be assumed that the aforementioned “eddy effects” may be the greatest. All attempts to calibrate the model such that this error at this location was reduced were not successful. The aforementioned error band is sufficient to deem the model calibrated. A profile plot of the calibrated baseline model is shown in Figure 3:

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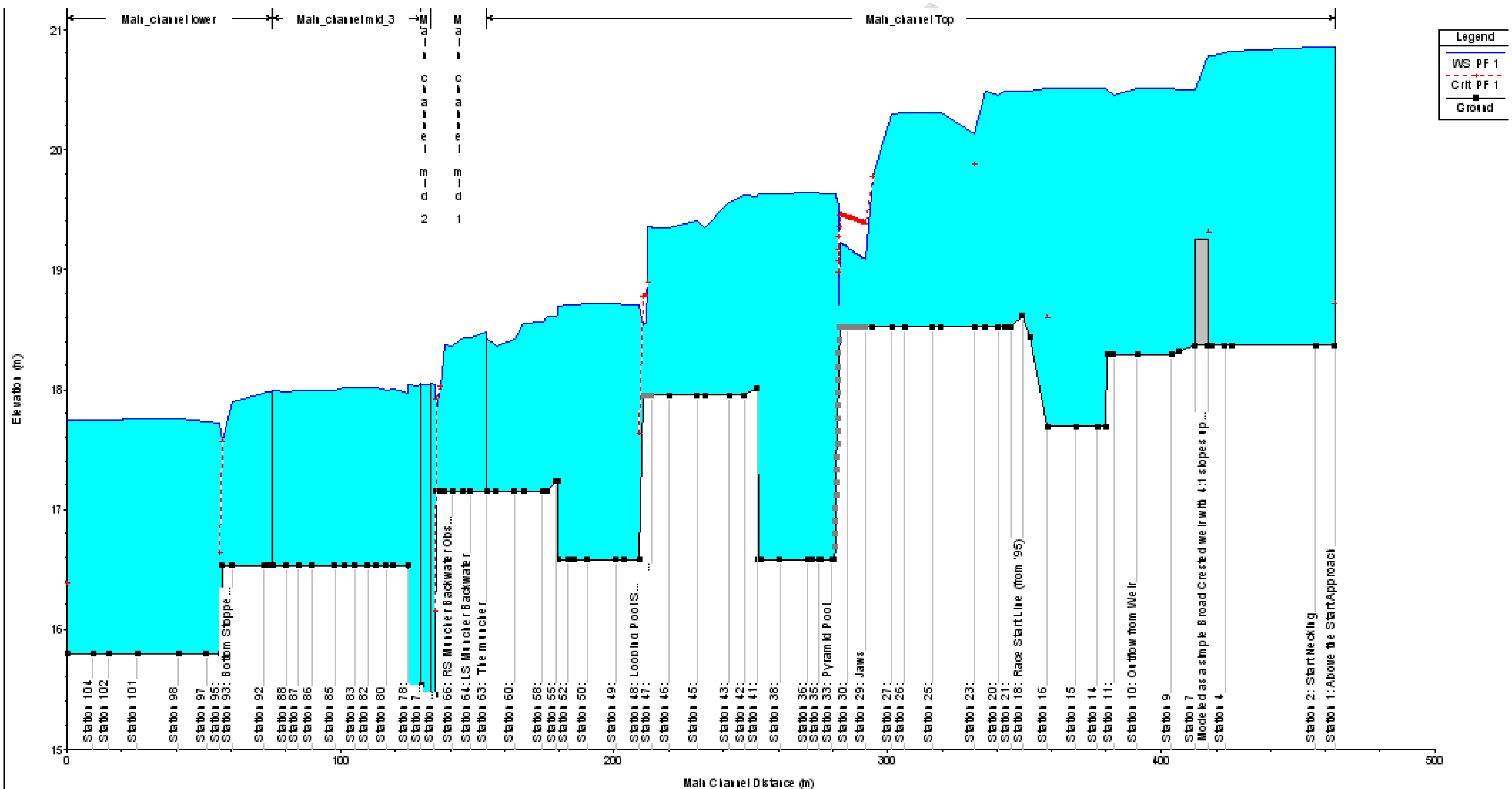

Figure 3. A Profile Plot of the Baseline Model of the Existing Holme-Pierrepont Whitewater Channel as Measured in Autumn 2008.

Proposed Changes to the HPP Whitewater Channel

There are a number of changes proposed for the HPP Channel that are intended to improve the performance of the channel. The proposed changes, shown in the order in which they were implemented in the model, include:

1. Step 1: Changes from Pool D downstream
    a. The infill of Pool D
    b. Addition of the wall between islands
    c. Removal of a large section of second island
    d. Addition of an eddy next to Muncher

2. Step 2: Changes from Pool C downstream
    a. The infilling of Pool C

3. Step 3: Changes from Pool B Downstream
    a. The widening of the run between Pools B and C and the removal of obstacles
    b. The infilling of the lower portion of Pool B.

4. Step 4: Changes from Pool A Downstream
    a. The moving of Jaws to the discharge point into Pool B
    b. The widening of the channel between pools A and B

5. Step 5: The addition of the Omniflot Obstacle System obstacles with the pegboards as permanent obstacles and the bollards in a likely configuration.

An illustration of the proposed course following changes is shown in Figure 4 Below:

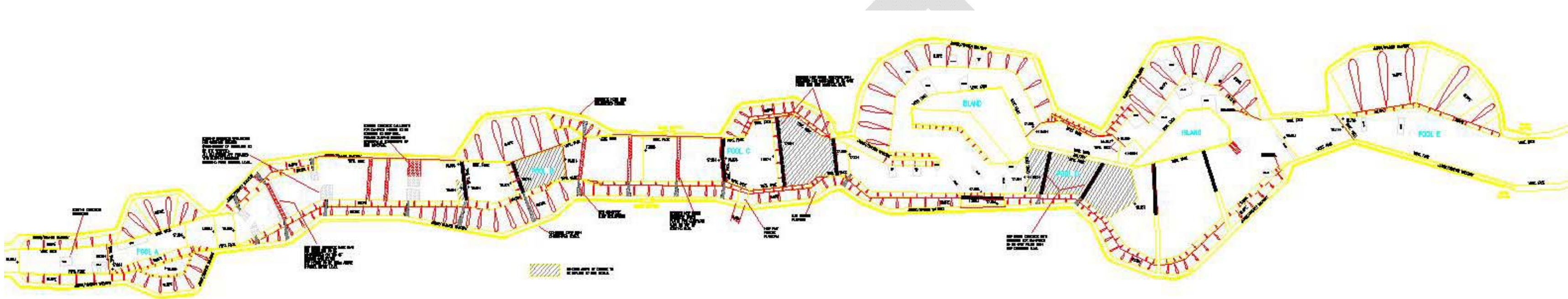

Figure 4. A Plan View of the proposed Changes to the HPP Channel showing In-Fill areas, removal of concrete obstacles, and placement of the Omniflot Obstacle System Evaluation of the Proposed Changes to the Holme-Pierrepont Main and Ancillary Channels

The proposed changes to the HPP Channel fall into three general categories. The first category includes the infilling of varying portions of HPP's relatively large and deep pools with the objective of increasing flow velocities across these pools. The second category of proposed changes is channel widening. In select sections of the course the cross-sectional flow area of the channel will be widened with the objective of both allowing more flow into the channel system and of creating greater opportunities for adjustability. The third category of proposed changes is the straightening and narrowing of a section of the course (located between the Muncher and the Bottom Stopper) to increase flow velocities through this region and decrease the amount of time that it takes to pass from one active whitewater section to another. It is the task of this study to evaluate how well the proposed changes meet these objectives and, further, to evaluate how these changes affect the portions of the course that are meant to be maintained in their existing configuration.

Due to the large degree of changes and the high degree of changeability of the channel it is difficult to isolate and evaluate whether the proposed changes will meet the desired objectives. As such this study has designed several tests which are implemented in the HEC-RAS model to establish that the design meets the following objectives:

The Infilling of the Pool Sections

1. Test 1: Verification that the pool infilling results in increased flow velocities in all, or portions, of the pool.

The Widening of Select Sections of the Channel System

2. Test 2: Verification that higher flows can be run in the course
3. Test 3: Verification that there will be increased changeability in the sections that have been widened.

The Narrowing and Straightening of the Channel between the Muncher and the Bottom Stopper:

4. Test 4: Evaluation of velocities and average flow time from the Muncher to the Bottom Stopper.

Preservation of Existing Features:

5. Test 5: Verification that the changes will not affect the character of flow in the Muncher Section.

The Infilling of the Pool Sections

Test 1: Verification that the pool infilling results in increased flow velocities in all, or portions, of the pool.

In the area surrounding Pool D it is the designer's intention to make the design more efficient and attractive to boaters by minimizing the low velocity flow region following the discharge into Pool D. It is the designer's intention to decrease eddy losses and to maintain the direction and magnitude of the flow's momentum by infilling the pool, providing a separation wall between the two islands, and by removing a portion of the second island in order to allow for more direct flow to the bottom stopper.

In order to isolate and evaluate the effects of pool infilling a model was created based on the Baseline Model but with Pool D in-filled. No other changes were made in this reach. This model was then run and compared to the Baseline model to evaluate whether there was an increase in flow velocities across the pool. Figure 5, below, shows a comparison of water surface elevations in this region before and after the changes:

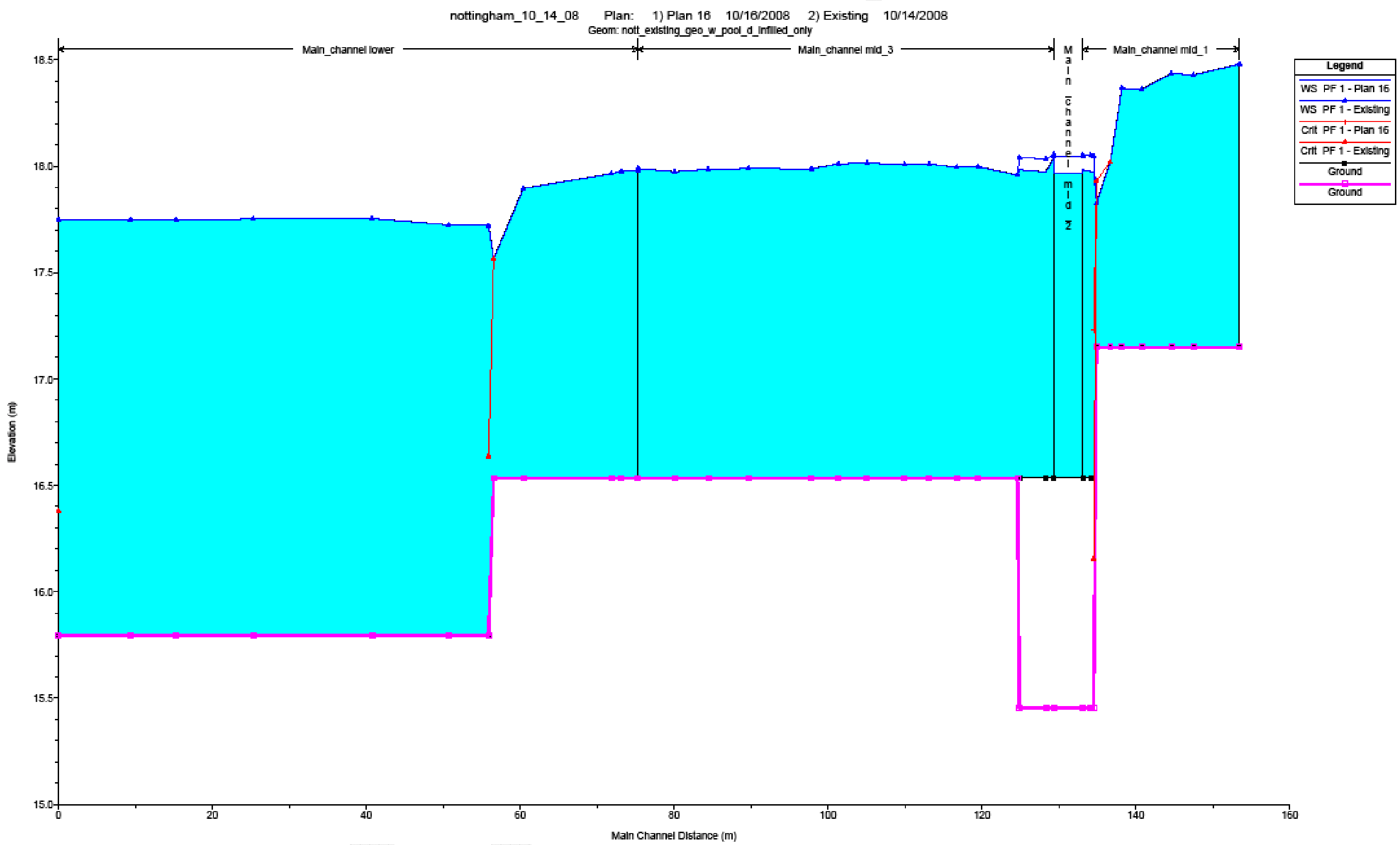

Figure 5. A Profile Plot of the Lower Portion of the HPP channel with Pool D filled in (black) compared to the Baseline Model (pink) showing decreased water surface elevations across the pool.

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Figure 5, above, shows that the in-filled areas in the modified model feature a slightly lower water surface elevation suggesting faster flows in this region. Numerical results suggest that flows in the modified model have a s much as a 10 cm lower water surface elevation than seen in the Baseline model. Another of the outputs from the HEC RAS model is expected average velocities. Numerical results from the model, plotted in Figure 6 below, compare the expected flow velocities across this section due solely to the infilling:

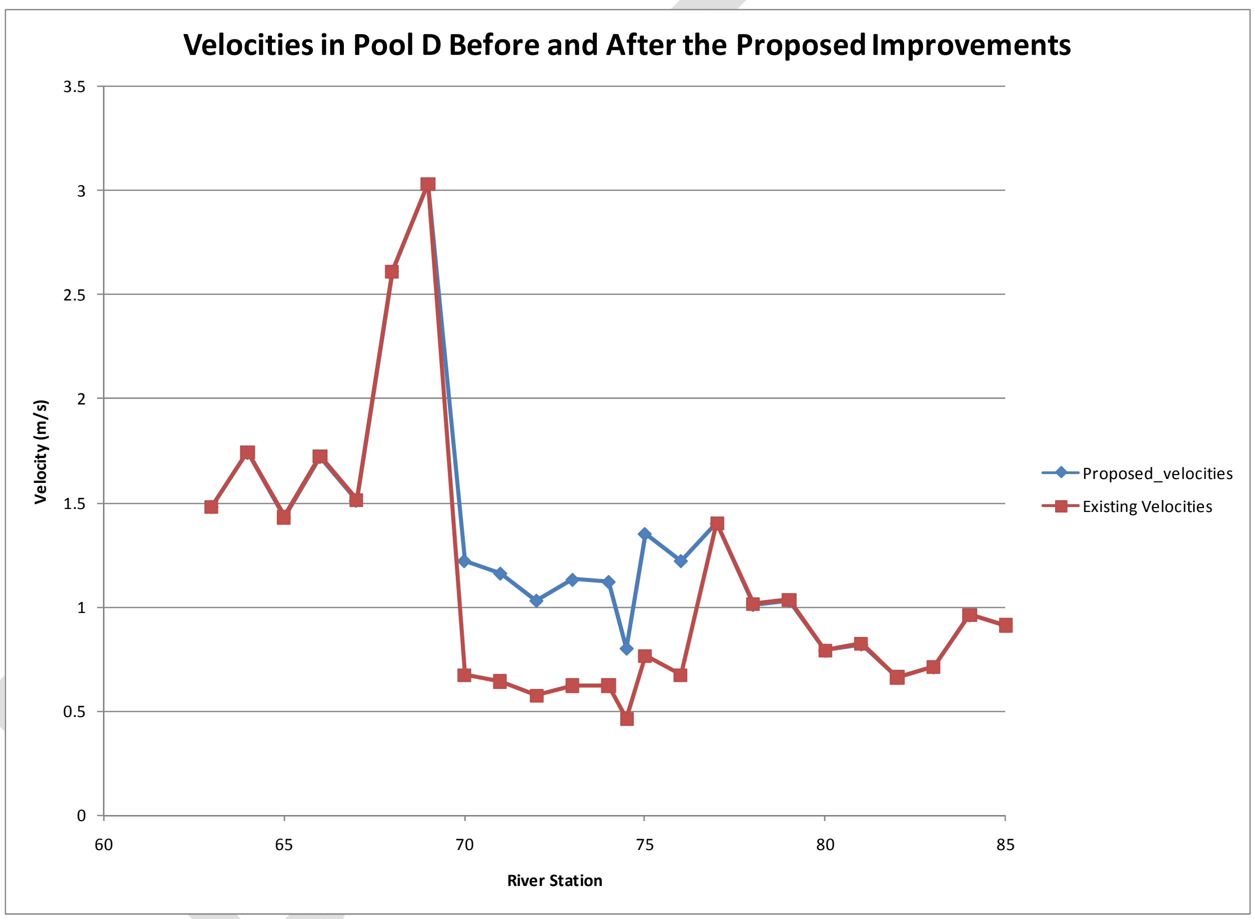

Figure 6. a comparison of flow velocities across Pool D shows that infilling will significantly increase expected flow velocities.

Figure 6, shown above, shows a significant increase in expected flow velocities. The maximum increase, seen at Station 75, shows an expected increase from .76 m/s to 1.35 m/s—an increase of roughly 77% These results suggest that the infilling of a pool section will dramatically increase flow velocities across the pool.

The Widening of Select Sections of the Channel System

Test 2: Verification that higher flows can be run in the course

One of the objectives of the proposed design changes is to increase the capacity of the channel system—to allow more flows into the channel. The calibration of this model found that the existing channel is flowing at approximately 17.5 cumecs. The design flow of the HPP channel is 24 cumecs –a flow rate many would like to see in the channel again following this set of improvements.

Typically channel capacity is simply a function of geometry. A certain amount of flow either fits, or doesn't fit, within the channel. This is not the sole variable at HPP because the channel is a bypass channel that splits off of an existing river. If the geometry of the channel is such that it causes a backwater effect that reaches the head gate structure at the top of the course then flows can be rejected down an alternate route—down the main river—and less flow will enter the course. This effect can be seen in the HPP Channel with the current configuration of the "Jaws" Stopper. The Jaws stopper clearly causes a backwater effect that drowns out many of the obstacles in the park and may have an effect on the amount of water that enters the HPP channel.

In order to evaluate if flows of 24 cumecs would flow naturally into the improved channel two tests needed to be checked. The first check is to evaluate if 24 Cumecs would enter the existing channel configuration if the dam is set to the right position. To test this aspect the upstream water surface elevation at 24 cumecs is compared to the upstream water surface elevation that was surveyed on the day the calibration survey was made. If the existing channel, at a flow of 24 cumecs, causes an upstream water surface elevation higher than the upstream levels surveyed, then it is rejecting flows from the channel back into the main river. The second check was to implement the Proposed changes, including the addition of groynes and pegboards, but not including the plastic Omniflots, and run 24 cumecs through this model. This check is to ensure that the Proposed course has the capacity, prior to adjustment, to accommodate flows of 24 cumecs.

In the first check the Baseline model was adjusted such that the head gate could accommodate flows of 24 cumecs on the day the calibration survey was made. The height of the head gate at the upstream end of the park was set to 18.65 m in elevation. This elevation was calculated such that flows of 24 cumecs would be expected to naturally flow into the HPP channel if the upstream water surface elevation was identical to that surveyed on the day calibration levels were measured. A test run was done of the Baseline model without obstacles and it was found

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that 24 cumecs did enter the channel. Furthermore, at the head gate elevation of 18.65 m, the upstream water surface elevation matched that surveyed in the autumn of '08 suggesting that the headgate had been set at the appropriate height.

To test the capacity of the existing configuration a flow of 24 cumecs was then run through the Baseline model with obstacles configured as they exist in the channel on the day of the calibration survey. Figure 7, shown below, illustrates the results of this model run:

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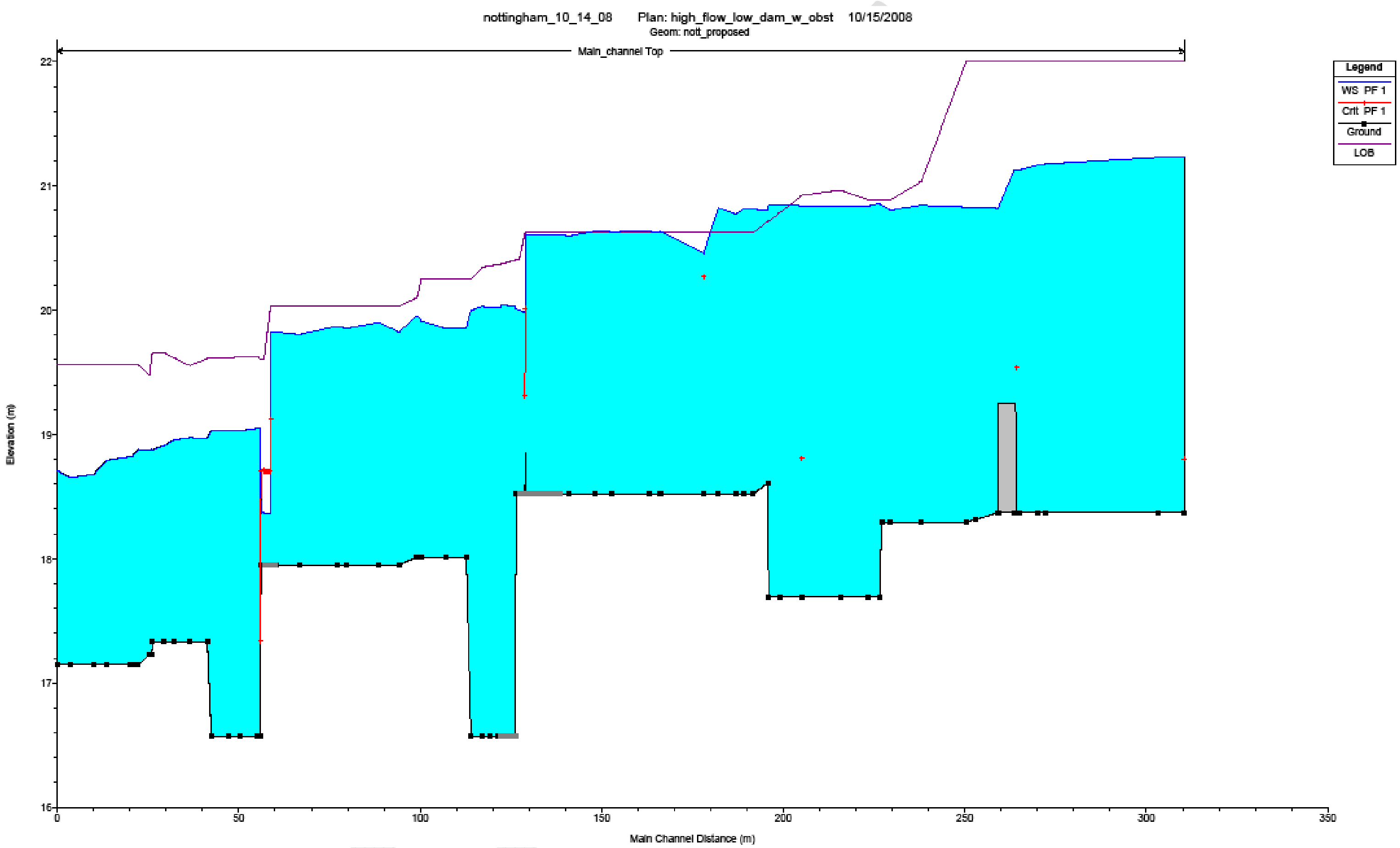

Figure 7. A flow of 24 cumecs caused a roughly 30 cm backwater above the head gate suggesting that sufficient flows cannot enter the channel at the existing level of constriction.

Figure 7, shown above, illustrates that the obstacles can have an effect on the headwaters above the channel. A measure at Station 4 above the dam showed a water surface elevation of 20.92 which is higher than the surveyed elevation at this station of 20.64. This effect is significant because the headwaters have alternative routes by which they can flow downstream. In reality, rather than raising the headwaters as seen in Figure 7 above, the channel simply accepts less water. This result, taken in the context of a test run that showed that 24 cumecs entered the channel without obstacles, suggests that the obstacles are the reason why existing flows have been found to be 17.5 cumecs.

The course was then configured with the Proposed obstacle system but with the Omniflots largely removed in the reach between Pools A and B, including the Jaws Obstacle. All proposed pegboards and groynes were maintained. The model was run again and it was found that there was critical flow at Station 23 making this Station the first controlling cross section below the Weir. Figure 8, shown below, illustrates the configuration of groynes and pegboards at this Section:

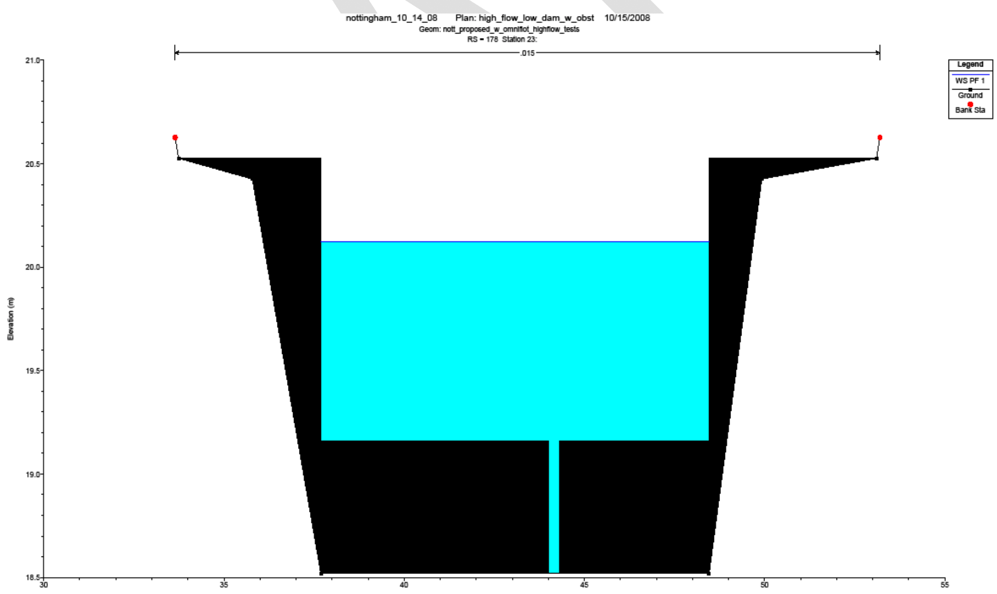

Figure 8. The first constriction downstream of the Weir as configured for maximum flow into the channels.

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When the Proposed Design was run in this configuration at 24 cumecs it was found that there was no negative effect to the water surface elevations upstream of the dam. Figure 9 shows this profile:

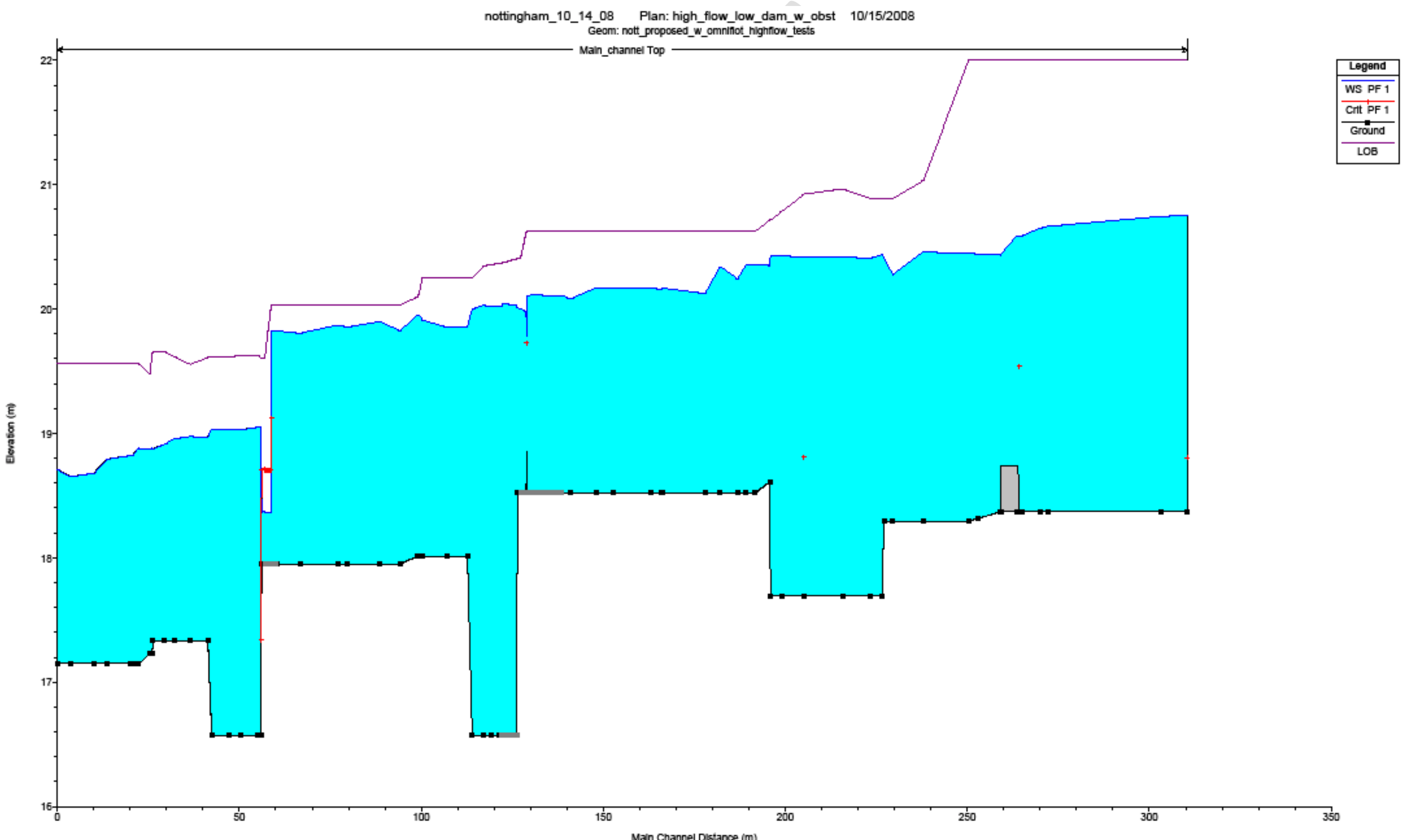

Figure 9. The Proposed Design with the Omniflot obstacles removed in the reach between Pools A and B at a flow of 24 cumecs does not negatively affect upstream water surface elevations.

In this Figure you can see that the course accepts the flow into the channel with very little backwater effect. The headwaters at Station 197 were found to be 20.65 in comparison to the Baseline Model headwaters elevation at Station 197 of 20.64 suggesting that 24 cumecs will flow into the Proposed Design channel if the Omniflot obstacles are configured correctly.

Test 3: Verification that there will be increased changeability in the sections that have been widened.

Another of the objectives of the study was to create a Channel System that offers greater adjustability. In the current configuration the moveable obstacle system allows for some changes but these changes are limited by the current width of the concrete channel in some areas and over-constriction issues in other areas whereby further constriction leads to the backwater flooding of upstream obstacles.

A measure of the increased adjustability of the channel system is to compare the difference in WSEs of the unconfigured channel—the channel without obstacles—to the configured channel—the channel as set up in a configuration that is attractive. Intuitively it makes sense that a channel that is very full cannot be constricted very much further without causing the channel to overfill or to back up. Conversely, a channel that is not very full can be highly constricted before these same backwater effects begin to take effect. Channels that can be highly constricted are more changeable and allow for more variety.

In order to evaluate the changeability of the course a similar experiment was conducted to that seen in Test 2. In the first part of Test 2 the amount of constriction was held fixed and the amount of flows were increased to evaluate the effects of backwater on the capacity of the channel. In this experiment the amount of flow is held fixed at 17.5 cumecs and the amount of constriction in the top section is varied from that seen in the current Baseline configuration to a configuration in which no adjustable constriction occurs in this reach. Figure 10, below, shows the comparison in results of these two model runs:

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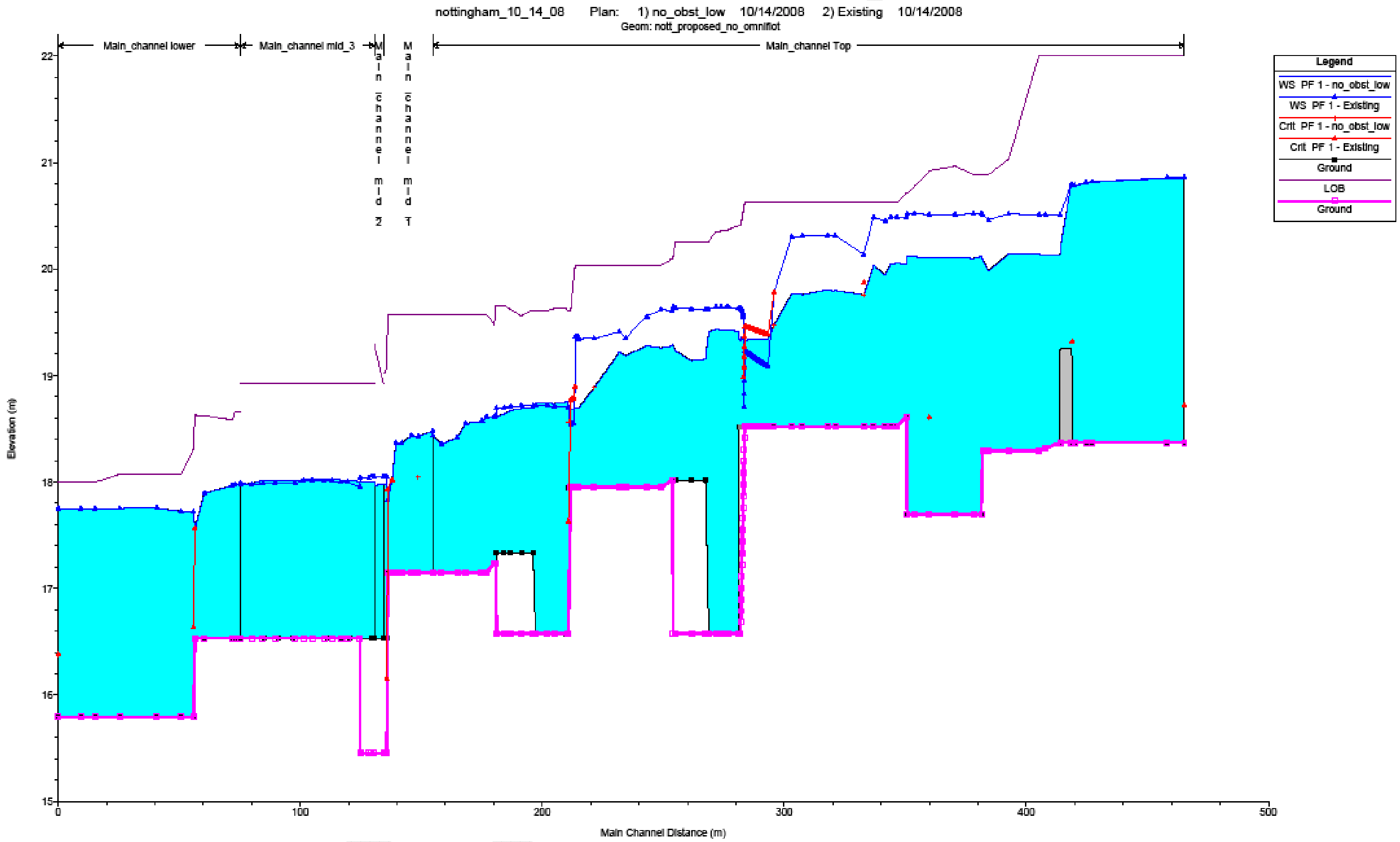

Figure 10. The Proposed Design, with no obstacles but run at 17.5 cumecs, compared to the Baseline Mode

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Figure 10, above, shows a dramatic difference in water surface elevations between the Proposed design and the Baseline Model. Based on this observed difference in water surface elevation it can be concluded that a great degree of constriction is available in this reach and, therefore, the course, in combination with a moveable obstacle system such as the Omniflot system, offers a large degree of variety.

The Narrowing and Straightening of the Channel between the Muncher and the Bottom Stopper:

Test 4: Evaluation of velocities and average flow time from the Muncher to the Bottom Stopper.

The proposed design includes the narrowing of Pool D as well as the removal of a portion of the lower island located just upstream of the Bottom Stopper. These changes were made with the design intent of maintaining momentum of flows across the reach between Pool D and the Bottom Stopper and to decrease the net paddling time between these two points. The momentum within this region can be ascertained through the average velocities in this reach—a standard output of HEC-RAS. The decrease in paddling time is less easy to specifically target since the speed of the potential paddler is not known. Figure 11, shown below, compares the average velocities of the flow within the reach beginning at the Start of Pool D and finishing at the Bottom Stopper:

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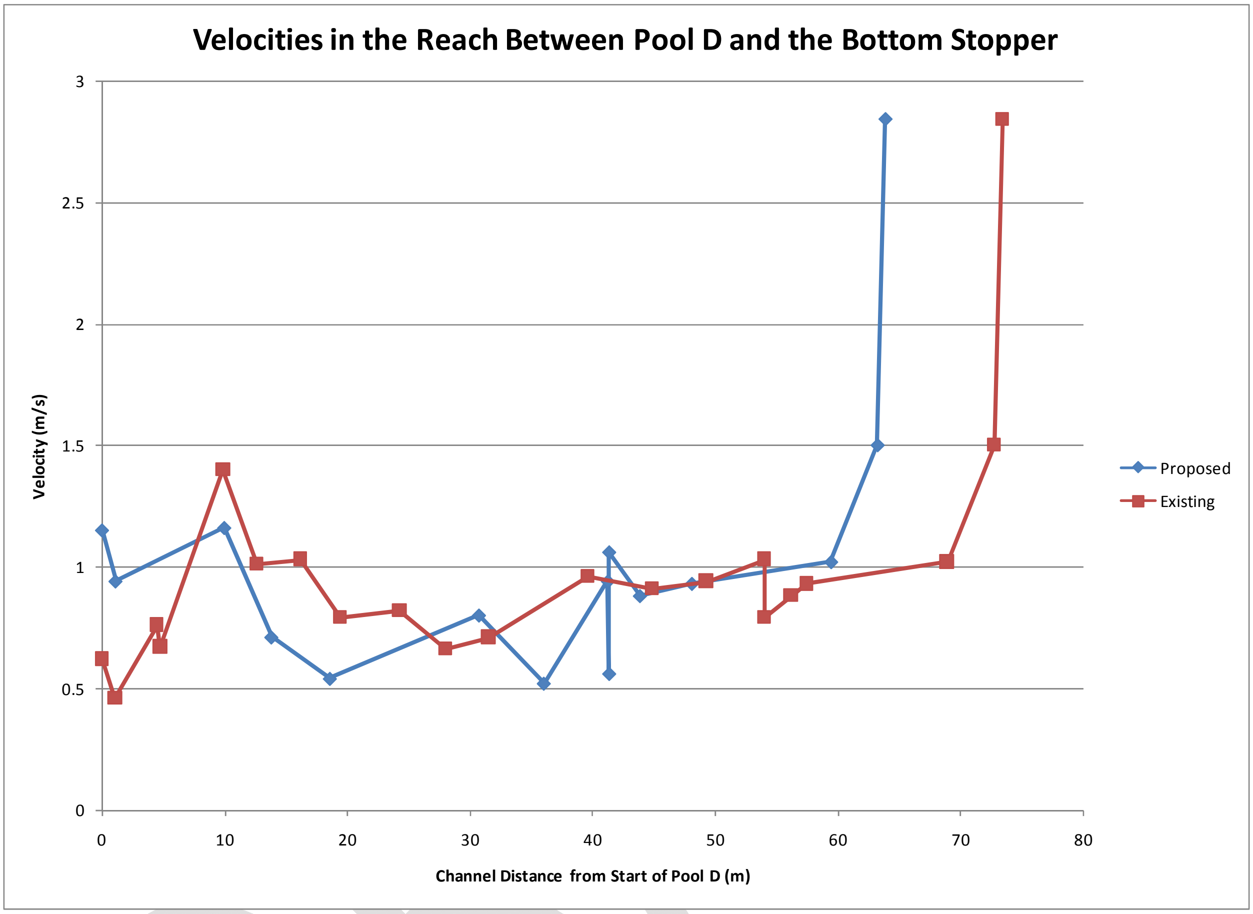

Figure 11. Average velocity versus distance from the start of Pool D for the Proposed vs. Baseline Models

Figure 11, shown above, shows that, in fact, there is not a significant increase in velocities across this reach. Following the increased velocities due to the infilling of Pool D, which are shown at the left hand side of this Figure, the Proposed model often features decreased velocities in comparison to the Baseline. However, the shortened distance is also significant to this discussion. If the average velocities at each station are used, in combination with the reach lengths, to calculate the float time for an element of water through this reach it is found that the Proposed Model can be floated approximately 4.7 seconds faster than the existing model. Therefore it can be concluded that the reconfiguration of this section does meet the objectives of decreasing the paddling time to the Bottom Stopper but does not appear to increase the velocities and momentum through this section significantly beyond the increases seen from the infilling of Pool D. It should be noted, however, that the inclusion of adjustable obstacles in this section will allow course operators to distribute some of the drop that is now located downstream of the Muncher into this reach. Such a change would increase the momentum of flows in selected parts of this reach.

The Preservation of Existing Features:

Test 5: Verification that the changes will not affect the character of flow in the Muncher Section.

One of the primary objectives of this study was to evaluate the effect of the proposed changes on the Muncher Section of the course (the reach between Pools C and D). Changes within this section were limited to the addition of an eddy to the true right of the Muncher, as seen in the proposed design drawings. Figure 12, shown below compares the expected water surface elevations in this reach before and after the proposed changes:

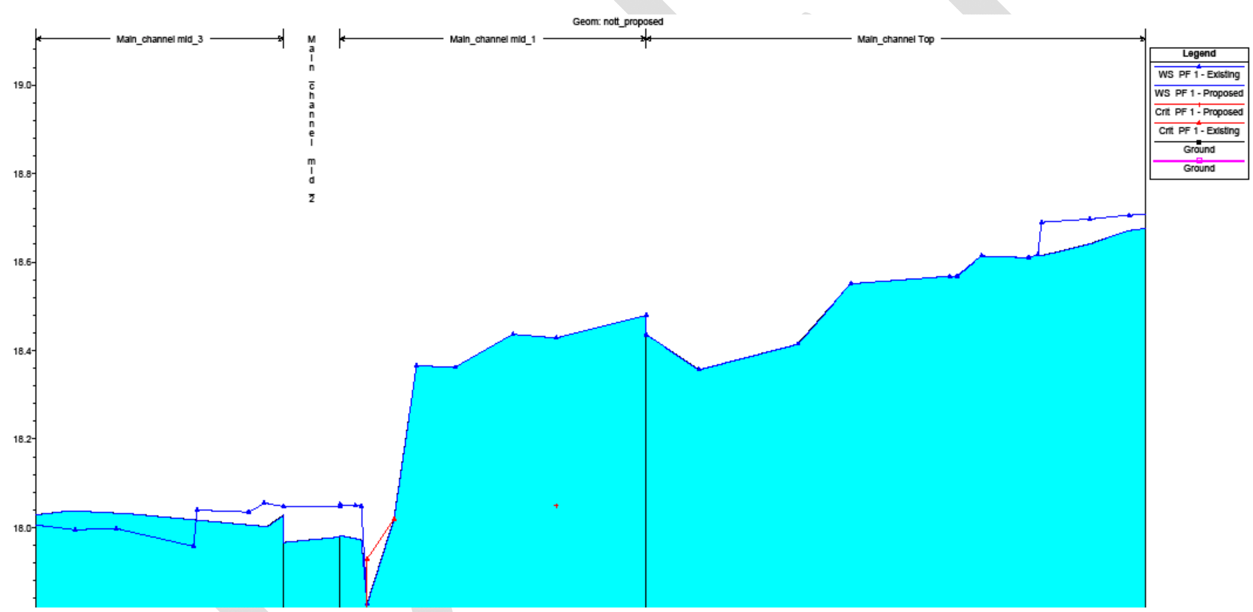

Figure 12. A before and after comparison of the expected water surface elevations within the Muncher Section between Pools C and D shows no difference in Water Surface Elevation.

This Figure shows that there is an effect at the Upstream end, due to increased velocities at the infilling of Pool C, and an effect at the downstream end, due to the infilling of Pool D, but that the water surface elevations are consistent throughout the reach between these two pools. A comparison of the modeled velocity distribution at the Muncher specifically is shown in Figure 13 below:

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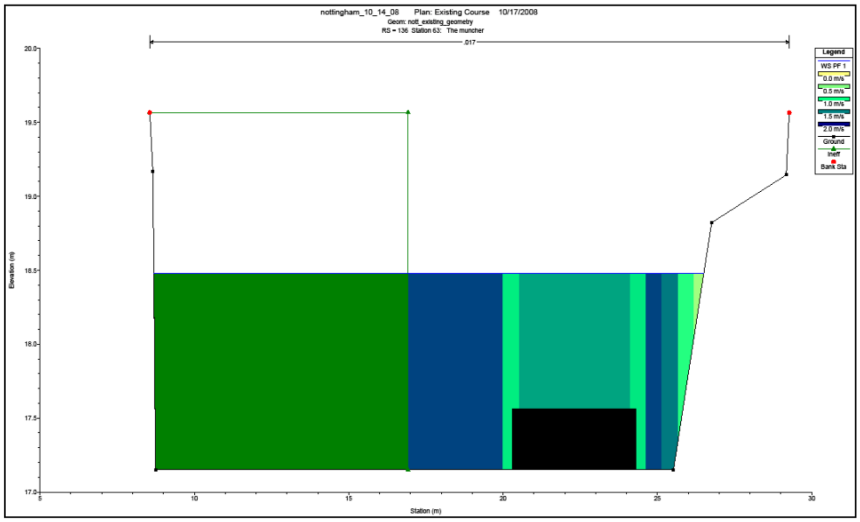

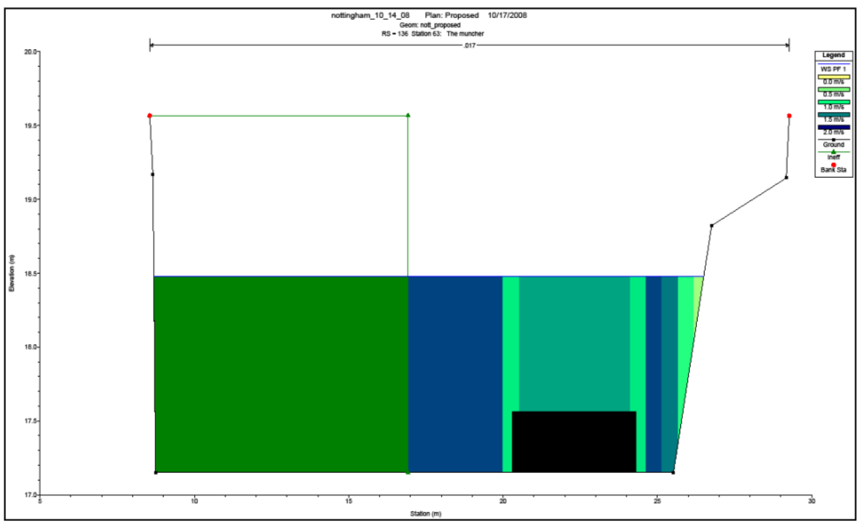

Figure 13. A comparison of the Velocity Distributions at the Muncher cross-section between the Baseline Model (top) and the Proposed Model (bottom) shows identical character and velocities.

Figure 13, shown above, illustrates the velocity distribution, plotted as isovals, at the Muncher cross-section. A comparison of the Baseline and Proposed models reveals flows that are of the identical depth, character, and velocity. Based on these comparisons it can be concluded that

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the proposed changes to the HPP Channel will have no effect on the Muncher Section

Conclusion

This study was tasked with using a one-dimensional flow model to evaluate the effects of proposed changes to the existing HPP channel with regards to specific objectives that were identified for this project. In order to evaluate these changes an existing conditions Baseline HEC-RAS model was created and calibrated to surveyed water surface elevations. A Proposed model was then created to reflect the proposed changes for the HPP channel. The Baseline and Proposed models were then perturbed in a series of specific tests designed to isolate and evaluate whether the proposed changes specifically functioned as intended by the designer.

The study concluded that:

- The infilling of the various pools does increase flow velocities across these pools within the HPP chanel.
- The widened channel areas between Pools A and C will allow for flows of 24 cumecs through the head gate and do have sufficient latitude for a high degree of adjustability.
- That the portion of the course that was straightened between the Muncher and the Bottom Stopper will pass boats more quickly through this typically slow section but will not result in increased velocities over and above those caused by the infilling of Pool D.
- That the proposed changes, taken in sum, do not affect the flow characteristics in the Muncher section of the course.