2012 Canadian Consulting Engineering Awards

Calgary Bow River Weir Project

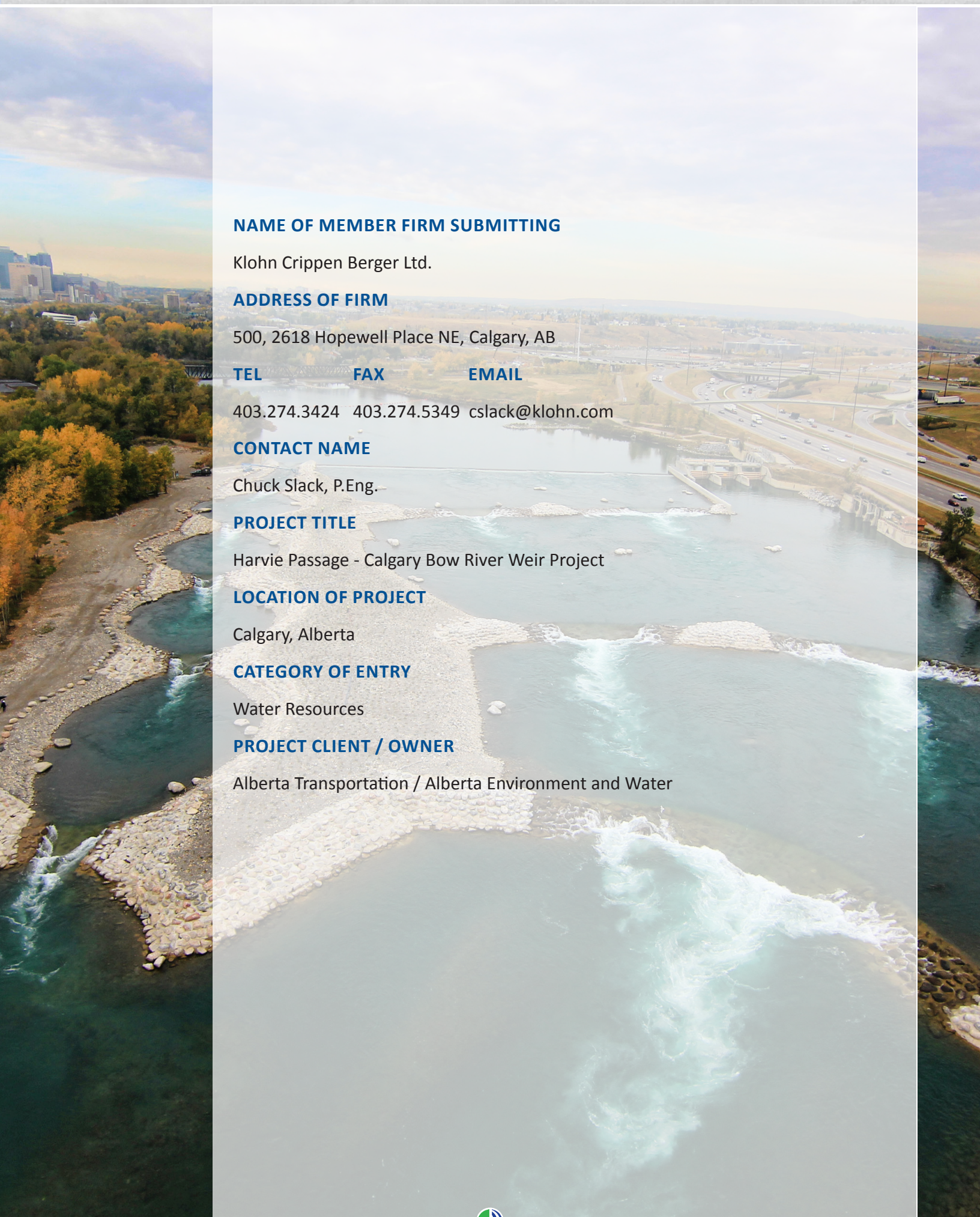
Calgary, Alberta

CANADIAN CONSULTING engineer

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES | CANADA

ASSOCIATION DES FIRMES D'INGÉNIEURS-CONSEILS | CANADA

Klohn Crippen Berger



NAME OF MEMBER FIRM SUBMITTING

Klohn Crippen Berger Ltd.

ADDRESS OF FIRM

500, 2618 Hopewell Place NE, Calgary, AB

TEL	FAX	EMAIL
403.274.3424	403.274.5349	cslack@klohn.com

CONTACT NAME

Chuck Slack, P.Eng.

PROJECT TITLE

Harvie Passage - Calgary Bow River Weir Project

LOCATION OF PROJECT

Calgary, Alberta

CATEGORY OF ENTRY

Water Resources

PROJECT CLIENT / OWNER

Alberta Transportation / Alberta Environment and Water

Calgary Bow River Weir

Submitted by: Klohn Crippen Berger

The primary purpose of the Calgary Bow River Weir project was to redevelop the weir to eliminate the extreme drowning hazard that it created and to enable river passage for non-motorized boats and fish while maintaining the Western Headwork's primary function of facilitating diversion from the Bow River to the Western Irrigation District. Modifications to the weir could not result in increased river levels upstream of the weir during river floods up to the 1:100 year flood event and project aesthetics were to be in keeping with the natural beauty of the Bow River.

Parks Foundation Calgary (PFC) commissioned the conceptual design of alternative design concepts to modify the Calgary Bow River Weir. PFC is a non-profit organization dedicated to the creation of parks, the preservation of river valleys, and the support of amateur sport. The conceptual design study concluded that a "full width man-made rapid" concept was a technically viable concept that offered the following significant benefits: increased safety and navigability; improved fish passage and habitat; reduced costs for Alberta Environment safety measures; reduced costs for the City of Calgary Fire Department Aquatic Rescue Unit, new recreational opportunities for whitewater boating, economic opportunities created by increased tourism to Calgary and area; and, aesthetic improvement as well as river, environment, and engineering educational opportunities.

In 2006, Klohn Crippen Berger Ltd. (formerly Mack, Slack & Associates Inc.) in association with their hydraulic and ice subconsultant, Northwest Hydraulics Consultants (NHC), and their recreational hydraulics subconsultant, Recreation Engineering and Planning (REP), were retained by Alberta Transportation to undertake the final design, contracting services, construction contract administration and resident engineering services and commissioning of the project.

To be able to continue its primary function of facilitating water diversions from the Bow River to the Western Irrigation District, the weir could not be removed, only modified. To improve safety and facilitate passage of non-motorized boats and fish, hydraulic constrictions (hereafter referred to as drop structures) were constructed downstream of the weir. The drop structures create a pool and riffle sequence resulting in higher water levels downstream of the weir; thereby, changing the hydraulics over the weir from a circulating hydraulic to linear. The hydraulic constrictions create energy through the riffles. The riffle geometry was designed to provide whitewater play areas for kayaking and river surfing thus making the safety improvements at the weir an amenity for the City of Calgary.

Two channels were constructed downstream of the weir. The Low Water Channel (LWC) on river right consists of six concreted boulder drop structures and five constructed pools to provide a bypass channel for novice boaters to pass downstream. The High Water Channel (HWC), located in the centre and left side of the river, consists of five concreted boulder drop structures and three constructed pools. The HWC provides whitewater play areas for more experienced boaters. The LWC and HWC are separated by a constructed divide island which provides bird habitat and refuge for boaters.

Fish passage enhancements include notches cut into the existing weir to facilitate boat and fish passage at low river flows, and lower velocity "fish passage channels" formed into the boulder-concreted surface of drop structures within the LWC and HWC. Fish passage boulders are incorporated in both the LWC and HWC drop structures.

The islands and concreted-boulder drop structures are relatively low profile (i.e. do not project very high above the river) and are designed to be overtopped by river flood events greater than the 1:2 year flood; thereby, ensuring that flood levels upstream of the weir, in downtown Calgary, are not increased by the weir modifications.

DESIGN - *Hydraulic Modelling*

The hydraulic design of the project utilized comprehensive physical models and 2D numeric computer modelling to assess overall project hydraulics (i.e. water levels, velocities, flow patterns, flood conveyance, and irrigation diversion delivery) and drop structure hydraulics (i.e. velocities, flow patterns, fish passage, playwaves, and scour potential). Physical model testing was performed at NHC's hydraulic laboratory in Edmonton. A comprehensive physical model of the entire project was constructed at a 1:50 scale. It reproduced an 850 m reach of the Bow River, extending approximately 350 m upstream and 500 m downstream of the existing weir. The model reproduced all pertinent features of the existing weir, canal headgate structure, sluiceway structure, and river channel bathymetry. The comprehensive model was used to validate and compare pre-project and post-project conditions for river discharges varying from a low flow of 44 m3/s up to the 1:100 year flood discharge of 2,750 m3/s. In addition to the comprehensive models, flume models of individual LWC and HWC drop structures at scales of 1:15 for the LWC drops and 1:22 scale and 1:12 scale for the HWC drops were constructed to provide more detailed indication of the hydraulic performance of the drop structures. The flume models were capable

of reproducing river discharges ranging from the low river flow of 44 m3/s to the 1:5 year flood discharge of 725 m^3/s.

Civil

The hydraulic design replicated in the physical model formed the basis for the sizing, geometry, and location of the drop structures, constructed pools, and islands. A comprehensive digital terrain model was created of the hydraulic model. This model aided in the generation of construction drawings, quantities and construction layout. The digital terrain model was subsequently used by the construction contractor for laying out the complex structures to a specified construction tolerance of ±25 mm.

A key component of the design was to blend the weir modifications with the natural surroundings of the Bow River. To do this required utilizing, as much as practicable, natural construction materials such as boulders, cobbles, and gravels. Conventional hydraulic structure designs with the desired design life of over 50 years would typically consist of man-made materials of reinforced concrete, structural steel, and/or steel sheet piles. To blend into the natural surroundings and to greatly increase the pace of construction, the design of the drop structures incorporated large, fieldstone boulders with macro-synthetic fibre reinforced concrete placed in the voids between the boulders for structural integrity and to reduce the risk of human limb entrapment. The concreted boulder structures more closely replicate natural riffles, outcrops, and bed materials that exist within the Bow River. Plastic fibre reinforcement was utilized to increase the tensile strength of the concrete to reduce thermal cracking of the concrete, provide structural integrity, and significantly accelerate construction. To allow barefoot pedestrian traffic on the structures, conventional steel fibre reinforcement was not applicable. Utilizing boulders with concrete in the voids provided very robust, cost effective structures with minimal foundation preparation resulting in faster construction with less care of water requirements and, ultimately, less construction impact on the aquatic environment than conventional reinforced concrete hydraulic structures.

The LWC and HWC drop structures are subjected to: continuous and varying flow in a relatively turbulent hydraulic environment; varying differential heads; ice action/effects; and, frequent freeze/thaw and wet/dry cycles. Consequently, boulder sizing was a critical element of the design. Boulders varying in equivalent spherical diameter of 1 m (1.4 tonnes) to 1.8 m (8 tonnes) were incorporated in the design. Modifications to the western headworks structures included extending the vertical slot fishway wall 60 m downstream to confine the pool downstream of the weir. Also, modifications to the existing weir included removing portions of the weir at four locations to create notches or entranceways into the LWC and HWC and constructing a 4 m long cast-in-place concrete section with a vertical drop along the downstream side of the weir to significantly reduce the submerged roller or circulating hydraulic.

The project was tendered in the summer of 2008 and was awarded to the low bidder, DeGraaf Excavating Ltd. (DGE) of Lethbridge, Alberta, for $16.6 million.

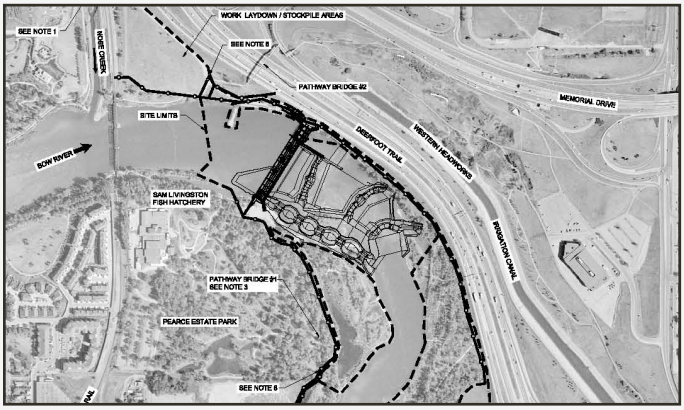
CONSTRUCTION

Construction started in December 2008 with the isolation and construction of the extension of the fishway wall which was completed in April 2009.

After completion of the fishway wall, in-stream construction structures were restricted from April 6th to 30th and July 15th to September 15th each year. In August 2009, DGE entered the river to construct cofferdams and a temporary diversion channel around three of the HWC drop structures and around the entrance to the LWC. Construction of the three HWC drop structures and entrance to the LWC was completed in April 2010. In April cofferdams were constructed to isolate the LWC to facilitate construction of the LWC which was completed in August 2010. Cofferdams were constructed to isolate the river on the remaining two HWC drop structures in September 2010 with construction being completed in November 2010. Cofferdams were removed in April 2011 and the project was fully functional on April 30, 2011. Construction was completed on schedule and under-budget.

Performance testing has been ongoing since May 2011. Swimmers, canoeists, kayakers, inflatable rafts and floaters have floated through and played on the drop structures. The weir was a safety hazard. Its transformation improves safety, fish passage, and creates an amenity to new users including canoeists, kayakers, bird watchers, educators, floaters, pathway users and picnickers.

Project History



Project location plan

The Western Headworks (WH) was constructed by the Canadian Pacific Railroad (CPR) in 1908 to divert water from the Bow River to the semi-arid region east of Calgary. The diverted water was, and continues to be, used for irrigated agriculture, livestock watering, municipal, and recreation, and served a pivotal role in the settling of Alberta and the population growth of Calgary and surrounding area. The original headworks structure, located on the Bow River within the Inglewood district of the City of Calgary near the current day intersection of Memorial Drive and Deerfoot Trail S.E., was constructed of timber. The weir and sluiceway structure were replaced with reinforced concrete structures in 1924. The 1924 diversion structure to the WH Canal remains today and has been designated an Alberta Heritage Site.

The 1924 structures were replaced by the Prairie Farm Rehabilitation Administration (PFRA), a division of Agriculture Canada, in 1975 and are now owned and operated by Alberta Environment and Water (AEW). The current headworks include a headgate structure (diverts water from the Bow River to the Western Irrigation District); a 152.4 m long x 2.6 m high ogee weir structure (the “Calgary Weir”); a sluiceway structure (used to divert the Bow River around the weir in the fall and winter); and, a vertical slot fishway structure located on the river left (north) end of the weir.

The “Calgary Weir” represented the only barrier to boaters and fish passage in the 100 km section of the Bow River between the Bearspaw Dam, located at the western limits of Calgary, and the Carseland-Bow River Headworks, located near the Village of Carseland, east of Calgary. The weir includes an ogee weir profile (like a ski-jump) which created a submerged roller or circulating hydraulic to reduce energy and flow velocities downstream of the weir. Since it’s construction, over 20 people have perished going over the weir as it is extremely difficult to swim out of the circulating hydraulic. Consequently, the “Calgary Weir” was named, with corresponding signage on site, the “Drowning Machine”.

Incorporating a fish ladder at the weir was quite progressive when the weir was commissioned in 1975. However, the 1.5 m wide vertical slot fishway had insufficient attraction flow to facilitate successful upstream fish passage on the 180 m wide Bow River. Fish populations were identified to be significantly different downstream and upstream of the weir, indicating that the weir was an obstruction to fish movement. The fish obstruction has resulted in the area downstream of the weir being a popular feeding area for pelicans and cormorants.

Warning sign (pre-construction)

Calgary fire department simulated rescue featured on the Discovery Channel Daily Planet (2009)

Project Overview

The primary purpose of the Calgary Bow River Weir Project was to redevelop the weir to eliminate the extreme drowning hazard that it created and to enable river passage for non-motorized boats and fish while maintaining the Western Headwork's primary function of facilitating diversion from the Bow River to the Western Irrigation District. Modifications to the weir could not result in increased river levels upstream of the weir during river floods up to the 1:100 year flood event and project aesthetics were to be in keeping with the natural beauty of the Bow River.

To this end, Parks Foundation Calgary (PFC) commissioned the conceptual design of alternative design concepts to modify the Calgary Weir. PFC is a non-profit organization dedicated to the creation of parks, the preservation of river valleys, and the support of amateur sport. The PFC was instrumental in the planning, vision, and fund-raising for the Calgary Bow River Weir Project.

The conceptual design study concluded that a "full width man-made rapid" concept was a technically viable concept with multiple benefits.

The preliminary design of the Calgary Bow River Weir Project was undertaken by Golder Associates, Northwest Hydraulic Consultants (NHC) and Recreation Engineering and Planning (REP) to further develop and confirm the dimensional design elements for the "full width rapid" concept. NHC of Edmonton carried out physical model studies to confirm the project hydraulic and safety performance, confirm irrigation diversion capability, and to assess non-motorized boat and fish passage and REP of Boulder, Colorado provided expert

Benefits of design concept

- Increased safety and navigability.
- Improved fish passage and habitat.
- Reduced costs for Alberta Environment safety measures.
- Reduced costs for the City of Calgary Fire Department Aquatic Rescue Unit.
- New recreational opportunities for whitewater boating.
- Economic opportunities created by increased tourism to Calgary and area.
- Aesthetic improvement as well as river, environment, and engineering educational opportunities.

input to the project configuration during the physical modelling with particular emphasis on the design of the whitewater play features. The results of the physical model studies, completed in 2006, were subsequently used to develop final designs for the required works, including modifications to the existing structures.

In 2006, Klohn Crippen Berger (formerly Mack, Slack & Associates Inc.) in association with their hydraulic and ice subconsultant, NHC, and their recreational hydraulics subconsultant, REP, were retained to undertake the final design, contracting services, construction contract administration and resident engineering services of the project.

Weir pre-project (2008)

Artist's drawing - courtesy of PFC

The project was carried out under direction from the PFC, Alberta Transportation (AT), The City of Calgary (City), and AEW. AT was the project manager for the project and played an instrumental role in design, tendering, construction, and commissioning.

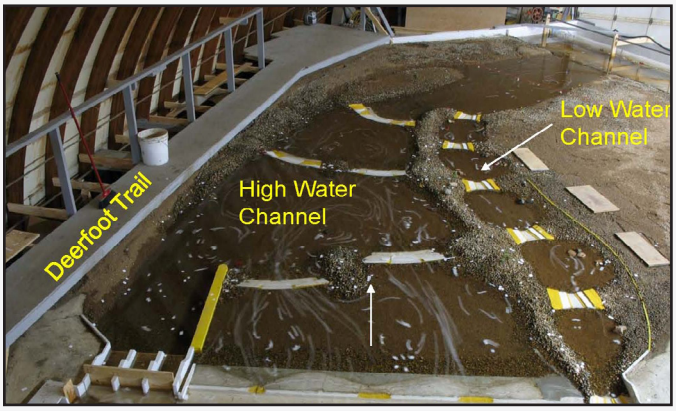
To be able to continue its primary function of facilitating water diversions from the Bow River to the Western Irrigation District, the weir could not be removed. Rather, the modified weir remains. To improve safety and facilitate passage of non-motorized boats and fish, hydraulic constrictions (hereafter referred to as drop structures) were constructed downstream of the weir. The hydraulic constrictions create a pool and riffle sequence resulting in higher water levels downstream of the weir; thereby, changing the hydraulics over the weir from a circulating hydraulic to linear.

The hydraulic constrictions create energy through the riffles. The riffle geometry was designed to provide whitewater play areas for kayaking and river surfing thus making the safety improvements at the weir an amenity for the City of Calgary.

Two channels were constructed downstream of the weir. The Low Water Channel (LWC) on river right consists of six concreted boulder drop structures and five constructed pools to provide a bypass channel for novice boaters to pass downstream. The High Water Channel (HWC), located in the centre and left side of the river, consists of five concreted boulder drop structures and three constructed pools. The HWC provides whitewater play areas for more experienced boaters. The LWC and HWC are separated by a constructed divide island which provides habitat for birds and refuge for boaters.

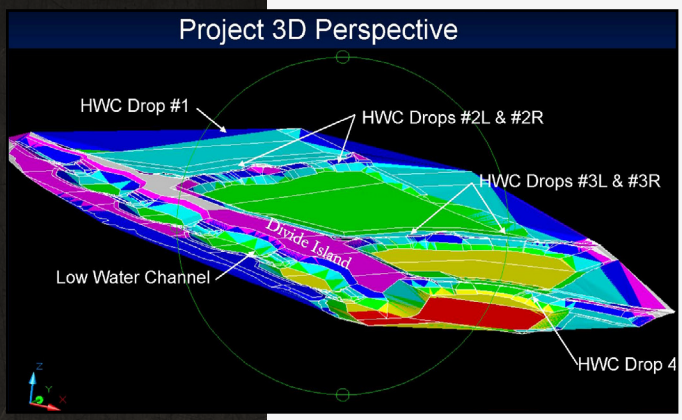
Fish passage enhancements include notches cut into the existing weir to facilitate boat and fish passage at low river flows, and lower velocity "fish passage channels" formed into the boulder-concreted surface of drop structures within the LWC and HWC. Fish passage boulders are incorporated in both the LWC and HWC drop structures.

The height of the islands and concreted-boulder drop structures are relatively low profile (i.e. do not project very high above the river) and are designed to be overtopped by river



Comprehensive physical model (1:50 scale) - courtesy of NHC (2006)

HWC Drop #3R flume model



Digital terrian model of projects

Placing boulder concrete (September, 2009)

flood events greater than the 1:2 year flood; thereby, ensuring that flood levels upstream of the weir are not increased by the weir modifications.

Design

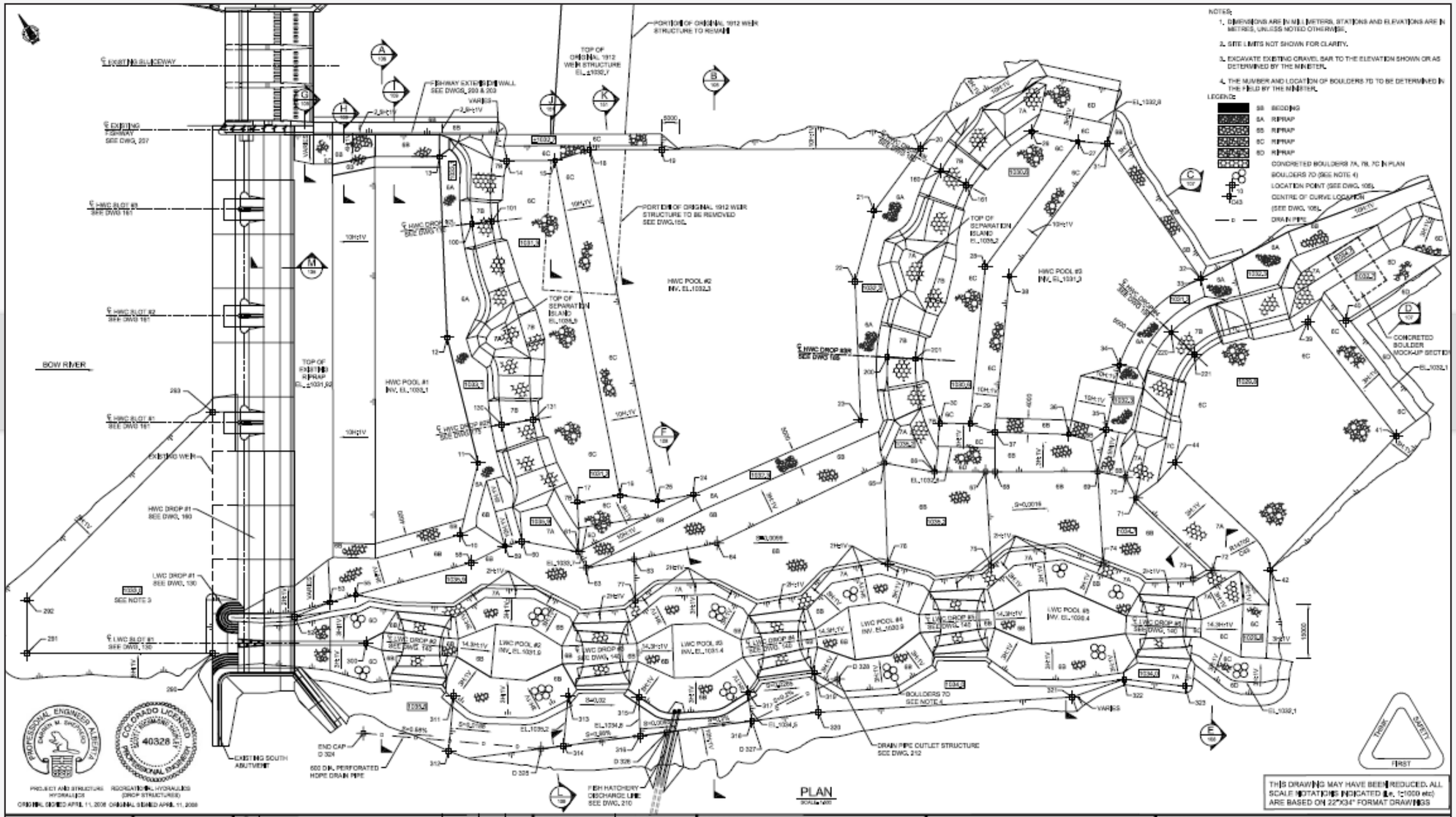
Hydraulic Modelling

The hydraulic design of the project utilized comprehensive physical models and 2D numeric computer modelling to assess overall project hydraulics (i.e. water levels, velocities, flow patterns, flood conveyance, and irrigation diversion delivery) and drop structure hydraulics (i.e. velocities, flow patterns, fish passage, playwaves, and scour potential). Physical model testing was performed at NHC's hydraulic laboratory in Edmonton. A comprehensive physical model of the entire project was constructed at a 1:50 scale. It reproduced an 850 m reach of the Bow River, extending approximately 350 m upstream and 500 m downstream of the existing weir. The model reproduced all pertinent features of the existing weir, canal headgate structure, sluiceway structure, and river channel bathymetry. The comprehensive model was used to validate and compare pre-project and post-project conditions for river discharges varying from a low flow of 44 m^3/s up to the 1:100 year flood discharge of 2,750 m^3/s. In addition to the comprehensive models, flume models of individual LWC and HWC drop structures at scales of 1:15 for the LWC drops and 1:22 scale and 1:12 scale for the HWC drops were constructed to provide more detailed indication of the hydraulic performance of the drop structures. The flume models were capable of reproducing river discharges ranging from the low flow of 44 m^3/s to the 1:5 year flood discharge of 725 m^3/s.

Civil Engineering

The hydraulic design replicated in the physical model formed the basis for the sizing, geometry, and location of the drop structures, constructed pools, and islands. A comprehensive digital terrain model was created of the hydraulic model. This model aided in the generation of construction drawings, quantities and construction layout. The digital terrain model was subsequently

Project General Arrangement Plan



Project was designed to blend with nature

Fishway boulders in HWC Drop #2L, (September, 2010)

LWC Drop #2 construction (June, 2010)

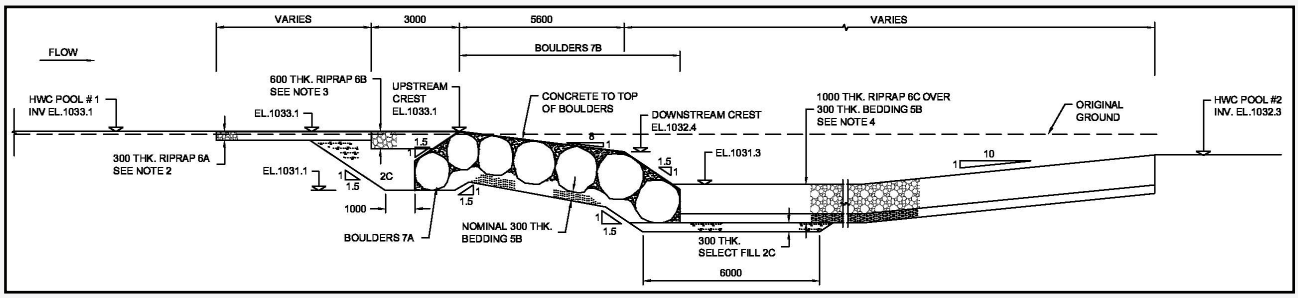
Half of HWC Drop #4 (October, 2010)

used by the construction contractor for laying out the complex structures to a specified construction tolerance of ±25 mm.

A key component of the design was to blend the weir modifications with the natural surroundings of the Bow River. To do this required utilizing, as much as practicable, natural construction materials such as boulders, cobbles, and gravels. Conventional hydraulic structure designs with the desired design life of over 50 years would consist of man-made materials of reinforced concrete, structural steel, and/or steel sheet piles. To blend into the natural surroundings and to greatly increase the pace of construction, the design of the drop structures incorporated large, fieldstone boulders with macro-synthetic fibre reinforced concrete placed in the voids between the boulders for structural integrity and to reduce the risk of human limb entrapment. The concreted boulder structures more closely replicate natural riffles, outcrops, and bed materials that exist within the Bow River. Plastic fibre reinforcement was utilized to increase the tensile strength of the concrete to reduce thermal cracking of the concrete, provide structural integrity, and significantly accelerate construction. To allow barefoot pedestrian traffic on the structures, conventional steel fibre reinforcement was not applicable. Utilizing boulders with concrete in the voids provided very robust, cost effective structures with minimal foundation preparation resulting in faster construction with less care of water requirements and, ultimately, less construction impact on the aquatic environment than conventional reinforced concrete hydraulic structures.

The LWC and HWC drop structures are subjected to: continuous and varying flow in a relatively turbulent hydraulic environment; varying differential heads; ice action/effects; and, frequent freeze/thaw and wet/dry cycles. Consequently, boulder sizing was a critical element of the design. Boulders varying in equivalent spherical diameter of 1 m (1.4 tonnes) to 1.8 m (8 tonnes) were incorporated in the design.

Modifications to the WH structures included extending the vertical slot fishway wall 60 m downstream



HWC Drop #2L profile

to confine the pool downstream of the weir. Also, modifications to the existing weir included removing portions of the weir at four locations to create notches or entranceways into the LWC and HWC and constructing a 4 m long cast-in-place concrete section with a vertical drop along the downstream side of the weir to significantly reduce the submerged roller or circulating hydraulic.

Tendering

The project was tendered in the summer of 2008. Bids were closed on August 28, 2008 and the construction contract was awarded for $16.6 million to the low bidder, DeGraaf Excavating Ltd. (DGE) of Lethbridge.

The project was privately funded with significant contributions by the Harvie family (the Calgary Bow River Weir Project is named Harvie Passage), Calgary Foundation, The City of Calgary, Alberta Lottery Fund, Alberta Environment, and Alberta Transportation.

Construction

Extension of fishway wall (April, 2009)

Construction started in December 2008 with the isolation and construction of the extension of the fishway wall which was completed in April 2009.

After completion of the fishway wall, in-stream construction activities were restricted to April 6th to 30th, and July 15th to September 15th each year. Construction activities ceased from May 2009 to August 2009 at which time DGE entered the river to construct cofferdams and a temporary diversion channel around HWC Drop #3L, #3R, and #4 and to isolate the entrance to the LWC. Construction of HWC Drop #3L, #3R and #4 were completed at the end of November. Construction of the entrance to the LWC (LWC Drop #1) was completed on April 14, 2010 and water was diverted over HWC Drops #3L, #3R and #4 for the first time on April 15, 2010.

In April 2010, cofferdams were constructed to isolate the LWC. Construction of LWC Drops #2 to #6 and LWC pools #1 to #5 started in April 2010 and were completed in August 2010.

Cofferdams were constructed to isolate the weir and HWC Drops #2L and #2R in September 2010. Construction of HWC Drops #2L and #2R were completed on October 22, 2010 and the weir modifications were completed on November 12, 2010.

Bow River diversion/construction of HWC Drops #1, #2L and #2R (October 2010)

Weir modfications (October, 2010)

Concrete debris fishway (April 2010)

Velocity measurements in river diversion

The cofferdams were removed in April 2011 and the project was fully functional on April 30, 2011.

Approximately 5,500 willow, dogwood and balsam poplar cuttings were planted on top of the divide island and along the left abutments of HWC Drop #3L and #4 in late April.

Construction was completed on schedule and under budget.

Project Commissioning

Performance testing started on HWC Drop #3L, #3R, and #4 in the summer of 2010 and continued on the entire project in May and June of 2011. Swimmer's, canoeists, kayakers, inflatable rafts, the Calgary Fire Department Aquatic Rescue Team, and floaters have floated through and played on the LWC and HWC Drop structures. Performance testing is ongoing as it is desired to test the structures through the full range of Bow River flows.

Planting on Divide Island (April, 2011)

Bow River diversion HWC Drop #3L, #3R and #4 construction (October 2009)

Kayaker testing

River raft testing

Floater testing

Low water channel

Collaboration

The Calgary Bow River Weir Project was a challenging and unusual project. Similar whitewater features to those incorporated in this project have been constructed elsewhere in North America (predominantly in the United States) but not on a river of this size or on a river with varying discharge and harsh ice regime as the Bow River.

Constructing a project that spans the entire width of the river presented interesting challenges. Limiting the impact of 30 months of construction on the aquatic environment was considered extensively in the design, as well as the selection of construction materials, construction methodology, technical specifications, construction activities and scheduling. Clean gravel cofferdams, turbidity curtains, settling ponds, erosion protection, numerous fish salvages, fish screens on dewatering pump intakes, provision of wildlife corridors through the construction site, and provision of upstream fish passage through all stages of construction attempted to reduce impacts on the adjacent environment. Collaboration with Alberta Transportation, Parks Foundation Calgary, regulatory agencies, stakeholders and the construction contractor (DGE) was essential to the successful completion of this project. Their input, guidance, and support is acknowledged and appreciated.

The weir was a safety hazard. Its transformation improves safety and fish passage and creates an amenity to river users including canoeists, kayakers, bird watchers, educators, floaters, pathway users, and picnickers.

Kayakers testing the rapids

Klohn Crippen Berger