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Hydrotechnical Design Guidelines for Stream Crossings

Introduction

Design of stream crossings and other in-stream highway facilities requires estimation of design highwater elevation and mean channel velocity. In cases where constriction of the channel is considered, such as most culverts or bridges with fills encroaching on the main channel, the resultant discharge is also required. These hydrotechnical design parameters should be consistent with the physical nature of the basin and channel, and within the context of historic flood observations in the basin and the hydrologic region.

Examination of long-term precipitation records indicate that, with few exceptions, the largest historic storms in Alberta that cause extensive flooding have typical volume (150 – 200mm precipitation near the eye of the storm) and timing (15 to 30 hours duration) values. The largest historic snowmelt events also appear to have typical volume and timing characteristics. The runoff response to these inputs may vary considerably over the province based on rainfall-runoff characteristics for each hydrologic region and the conveyance/storage characteristics of each basin.

The design hydrotechnical parameters should be representative of the response to such a large flood event at the design site. This requires consideration of historic highwater observations in the hydrologic region and assessment of the site-specific response based on the nature of the basin and the nature of the channel supplying the flows to the site. The following techniques can be used to determine hydrotechnical design parameters for stream crossings :

- Channel Capacity
- Historic Highwater Observations
- Basin Runoff Potential

All three techniques provide a different way of estimating the nature of the largest historic response at a site. The channel capacity technique considers the physical capacity of the channel being crossed, which is a result of the flow history over an extended period of time. The historic highwater observations technique directly considers historic data. The basin runoff potential technique applies the largest historic runoff data collected at gauge sites in the hydrologic region as an upper bound to the supply of runoff to a site. Therefore, the resulting design parameters can be considered “equivalent to the largest historic event”. A return period (or probability of exceedance) is not required.

These hydrotechnical design parameters should be used for the evaluation of all proposed crossing alternatives at a site. Selection of the optimal solution will be based on consideration of performance under the design flow conditions. Factors such as roadway importance, likelihood of damage to the crossing, and susceptibility of upstream property to flooding should be taken into account (see “Culvert Sizing Considerations” document).

Channel Capacity Analysis

Channel capacity can be considered by assigning a design highwater elevation to a crossing based on channel geometry. This is a useful technique for many streams in Alberta, where considerable overbank storage exists beyond the bankfull capacity of the channel. By implicitly accounting for flow routing at higher stages, this simple technique can quickly establish a reasonable range for the design hydrotechnical parameters at a site.

Assessment of the channel capacity requires identification of typical channel properties at bankfull stage, estimation of the channel slope (S), and assignment of a channel roughness parameter. Estimation of typical channel properties involves assessing properties such as bank height (h), bottom width (B) and top width (T) at several locations in a reach. Ideally, these properties will be for cross sections at relatively straight portions of the reach, as channel geometry can vary considerably at sharp bends. Also, cross-sections located in close proximity to existing bridge structures may not be representative of the typical cross section as they may have been modified during construction.

The bank height refers to the depth at which there is a significant break in the cross section perpendicular to the direction of flow, so that significant activation of overbank storage would start to occur as the stage rises. Identification of bankfull stage can usually be made from site observations and surveyed cross-sections. Site photos, inspection reports, large-scale airphotos, and contour maps can assist in identifying typical channel properties. In general, the top width of water inundation at depths exceeding the bankfull stage by 0.5m to 1.0m should be several times the bankfull top width.

The flow depth (or highwater elevation) for channel capacity calculations can be assigned at a certain depth above bankfull stage. It appears reasonable that a certain minimum depth above bankfull is required in order to activate overbank storage at any site. The depth above bankfull at a specific site would depend on the amount of overbank storage available and how quickly that storage is activated with increasing flow depth. A recent study comparing observed highwater elevations to bankfull stage (based on the AT Design Data drawing inventory) shows that there are few sites with observed flow depths exceeding the apparent bankfull depth by more than 1.5m. Most of these few exceptions, include backwater caused by the crossing or have relatively narrow floodplains. This study also noted that for smaller channels, the maximum observed flow depth seldom exceeded bank height by more than 50%.

Based on these observations, it is recommended that the flow depth (Y) for channel capacity purposes be set as follows :

- $h < 1.0m$, $Y = h + 0.5m$
- $1.0m < h < 2.0m$, $Y = 1.5 * h$
- $h > 2.0m$, $Y = h + 1.0m$.

The channel slope (S) for many streams in Alberta can be extracted from the "*HIS*" tool, based on profiles derived from DTM data. For streams that have not been profiled within HIS, the slope can be estimated from DTM data-sets and a GIS tool such as Global Mapper.

A roughness parameter is not required for wider channels if the AT equation is applied (see "*Evaluation Of Open Channel Flow Equations"* document). However, smaller channels will require some form of roughness parameter due to the irregularity of these channels and the significance of bank roughness. The following values of roughness coefficient (n) for use with the Manning equation are recommended :

B : 0 – 3 m, n = 0.05
B : 4 – 6 m, n = 0.045
B : 7 – 9 m, n = 0.04
B > 10m, use AT equation

During development of the AT equation, it was observed that the Manning equation slope exponent limits its application to a range of slopes, which is usually accommodated by modifying the roughness coefficient. Therefore, the following approximate corrections are suggested to be applied to the above base values for 'n' :

$S < 0.0005$ (B >8m), $n = n – 0.005$
$0.005 < S < 0.015$, $n = n + 0.005$
$S > 0.015$, $n = n + 0.01$

The "*Channel Capacity Calculator*" tool combines the flow depth rule with the typical channel geometry and input slope and roughness to estimate design parameters for Y, V, and Q.

The flow estimate generated by this technique is for the main channel only, and will not include flows adjacent to the channel on the floodplain. In most cases, this will be sufficient, as the velocities on the adjacent overbank should be quite low due to the shallow depths of flow, lack of consistent flow path, and interaction between the storage and the main channel (see "*Practical Hydraulic Modelling Considerations*" AT, 2006).

Historic Highwater Observations Analysis

Historic highwater observations at a site can provide valuable insight to the hydrologic and hydraulic response of a natural basin and stream to a large runoff event. The "*HIS*" tool includes a compilation of much of the historic highwater data collected by AT including high water levels, descriptions and photos. Although not yet comprehensive, the existing database includes a lot of flood response information and delivers it in an easy to use manner. Nearby sites, both upstream and downstream can be easily located and checked for information.

Additional sources of highwater information include :

- AT Correspondence file – these files, available at both the Twin Atria office and in each region, contain a record of many observations and work history documentation for each site. In many cases, flood information not yet in the database will be on the file, and often more detailed descriptions of the event and its impact will be found. Many file history summaries have been compiled and are available within the "*HIS*" tool.
- AT Design Documentation – additional bridge planning information may also be available which may provide insight into flood responses that the bridge planner was aware of and how these were incorporated into the bridge plan. This information may be in the form of design folders, consultant reports, and drawings. Particular attention should be paid to noted historic floods and flow estimates based upon them.
- Local Information – in many cases, nearby residents and local officials may be able to provide some flood response information. Residents may be able to provide photos detailing the year and extent of a flood or possibly note marks on buildings. Accounts from memory may also be available, but these should be verified by other means. Local officials may be able to provide details of emergency response such as closing and repairing bridges. Local newspaper archives may also provide photos and accounts of the impact to the people in the area.
- Alberta Environment - AE have collected flood response information at many sites, especially areas where they have done in-stream works. They also may have historic flow information for sites impacted by engineering structures.
- Airphotos – in some cases, airphotos may have been obtained close to the peak of a flood. These airphotos may be available from Airphoto Services of Alberta Sustainable Resource Development. A review of historic airphotos may also indicate the approximate timing of significant historic flooding due to observed channel changes, such as channel relocations, bank instability, dimension changes etc.

In addition to highwater level data, additional types of information may be available, including :

- source and location of highwater estimate
- backwater from downstream controls

- impact of operation of hydraulic structures
- velocity estimates
- horizontal extent of flooding
- headloss across a structure
- scour depths
- channel changes – alignment, section, profile
- drift blockages
- ice thickness
- damage to structure during event.

All of these factors can have a significant effect on the hydraulics of flow under highwater conditions, and should be accounted for in any flow estimates based on the highwater information.

Knowledge of the general flood history of an area can be helpful in focusing attention to a specific site. Approximately 140 storm contour maps have been developed based on published Environment Canada data. The *AT "Storm on Basin*" tool can be used to graphically visualize the storm contours from any of these storms on top of a basin. It will also produce a sorted list of rainfall on a specified basin for each storm in the database. This facilitates identification of likely response years, as well as assessing the significance of these events. Approximate basin boundaries can be based on the location of the centre of the basin (longitude, latitude coordinate) and the drainage area. Alternatively, the basin boundary for a nearby WSC gauge can be retrieved from the database.

The "*PeakFlow*" tool can also be used to query available runoff data collected and published by WSC. This tool provides access to all published annual maximum flow data, as well as calculated hydrograph parameters for many of the largest events. Rating curve data and the actual gauging measurements used to build them are also available for many sites. This information is useful for identifying large runoff events in an area, as well as providing specific highwater and hydraulic data for gauged sites.

Additional information on the hydraulic adequacy of an existing structure can also be obtained from site inspection and maintenance history from the correspondence file. Features that may be associated with hydraulic inadequacy include scour through a bridge opening or downstream of a culvert, culvert uplift failure, and the frequency of the need to remove drift, repair protection works and channel banks, conduct scour inspections, and deal with concerns of local landowners.

The confidence in available historic highwater data should be assessed based on the information available and correlation with other data sources (i.e. runoff and precipitation records). Any influences on these observations that may not be applicable to a new crossing at the site should be identified and accounted for. These may include bridge backwater, drift blockage, or ice impacts. Structure influence may be assessed using tools such as *HydroCulv* or *Flow Constrict* (see "*Practical Hydraulic Modelling Considerations*" document).

Basin Runoff Potential Analysis

In some cases, the runoff response at a site may not reach the channel capacity estimate under design conditions due to limitations in the runoff supply in the hydrologic region, or runoff routing effects from the upstream basin and channel.

Runoff supply limitations can be easily identified using unit discharge techniques based on design runoff loadings (*Runoff Depth Map*). Unit discharges can be estimated for each area on the runoff depth map as follows :

$q\ (\text{cms/km}^2) = d/(3.6*T_p)$

where 'd' is the design runoff depth (mm) and 'T_p' is the associated time to peak (hours). For example :

$d = 35$ mm, $T_p = 40$ hrs, $q = 0.25$ cms/km^2
$d = 40$ mm, $T_p = 20$ hrs, $q = 0.55$ cms/km^2
$d = 60$ mm, $T_p = 20$ hrs, $q = 0.83$ cms/km^2
$d = 80$ mm, $T_p = 20$ hrs, $q = 1.1$ cms/km^2

The upper bound to peak flow based on runoff supply, assuming no significant routing in the basin, can then be estimated by :

$Q_p = q * DA$

where DA is the gross drainage area for the basin (km^2). Many basins will cover multiple hydrologic regions as identified on the runoff depth map, and a composite 'q' value will be required.

An example of a situation where runoff supply would govern design would be a small drainage area feeding into a steep channel with high banks, possibly due to down-cutting to meet a receiving stream. As with previous runoff depth routing techniques, these values are not applicable to larger basins ($DA > 3000$km^2), and will seldom govern for $DA > 100$km^2.

Routing effect limitations, such as due to a large u/s lake, can be assessed using routing calculations (e.g. *HydroNetwork* tool). Although inflow hydrograph parameters can be estimated from runoff depth map values (volume and timing) and stage storage curves can be estimated from lake geometry, the outflow rating curve is often difficult to determine. Therefore, application of routing calculations is only recommended for sites where the outflow rating curve can be reasonably approximated based on historic information of lake levels and corresponding outflows or engineering information on outlet control structures.

In some cases, the runoff potential may be governed by u/s channel routing impacts, such as a low capacity channel entering a high capacity ravine. In such a case, the runoff potential for a site within the ravine section could be estimated by adding the channel capacity estimate for the u/s channel to the runoff supply potential flow for the drainage area that drains directly into the ravine section.

Assigning Design Hydrotechnical Parameters

The results from each of these three types of analysis should be considered, where applicable, in determination of the design hydrotechnical parameters (flow depth (Y). mean channel velocity (V), Flow (Q)) for a stream crossing. In general, basin runoff potential will govern for sites with small drainage areas or steep channels. Channel capacity will govern for sites with extensive overbank storage. Historic observations will likely govern for sites with large drainage areas or less extensive overbank storage. In many cases, the historic observations can be used to guide selection of typical channel properties.

As the amount of historic and channel observation data varies from site to site, it is useful to identify like reaches of a channel and make use of data and analysis results at some sites for guidance at other sites. Identification of like reaches can be assisted by delineating drainage area and slope for all bridges on a stream (information for many sites is available with the HIS tool).

These techniques have been applied to many sites and examples may be accessed through the Hydrotechnical Information System (*HIS*) tool as hydrotechnical summaries.