Analyzing and Projecting Post-Flood Vegetation Colonization along the Bow River through Calgary, Alberta

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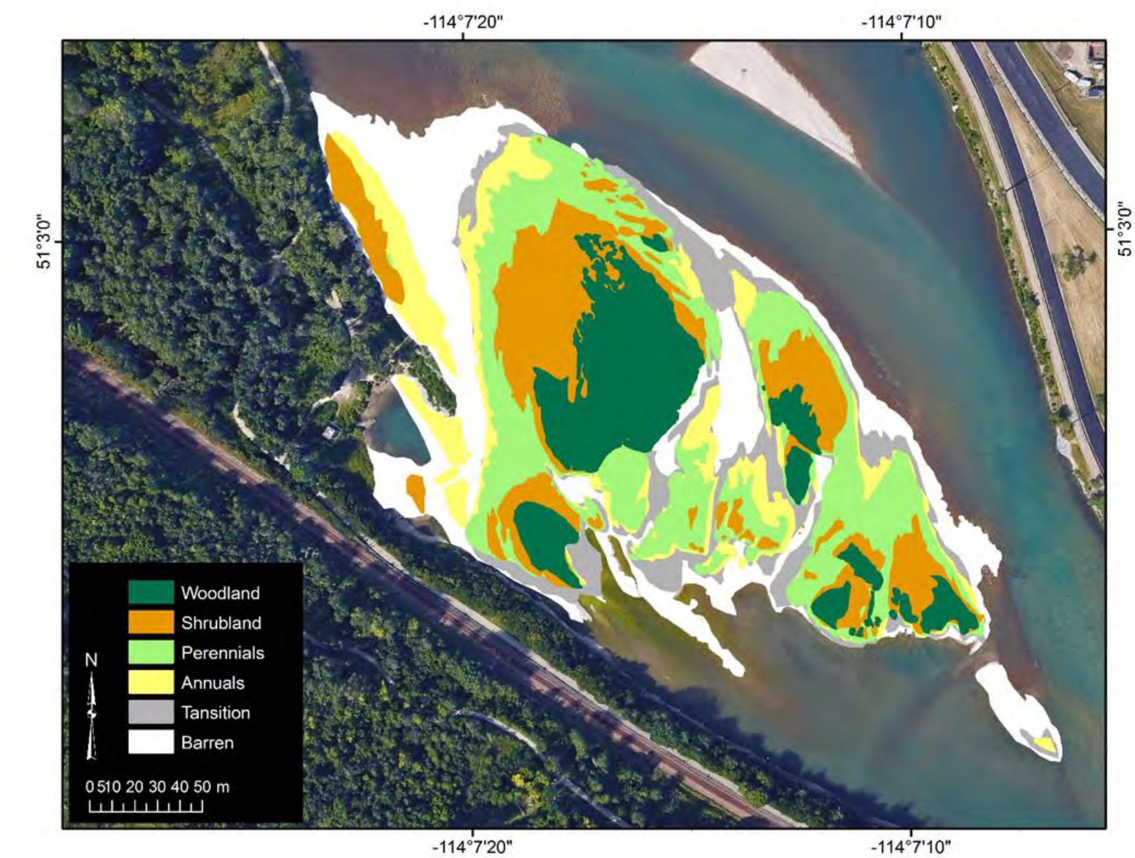

Summary

After eight decades without a major flood, extreme rains of June 2013 resulted in the highest flows of record (since 1912) along the Bow and Elbow Rivers through Calgary. This major flood produced extensive erosion, transport and deposition of gravels and other alluvial sediments, resulting in the formation, elevation and expansion of some gravel bars and islands. The newly deposited sediments were initially barren of vegetation and there will be progressive colonization and succession of riparian plant communities on some of these surfaces.

Concern arose relative to the prospect that woodland development at some locations could impede high river flows and thus elevate bank erosion or overbank flooding with future flood events. To investigate this prospect, we undertook studies to characterize the patterns of vegetation colonization and subsequently to project where woodlands (with trees), shrublands or other riparian vegetation communities would develop. We emphasized potential problem locations that had been previously identified within the *Calgary Rivers Morphology and Fish Habitat Study*.

We analyzed eleven locations along the Bow River and one location on the Elbow River, as well as observing general conditions along both river corridors. We found extensive seedling colonization by riparian plants with balsam poplars being most common. We found that willows uniquely survived through the major flood, providing shrub patches that are likely to expand, and willow seedlings were also abundant. Weed seedlings were common, including some noxious plants. We were especially concerned with colonization by reed canarygrass along the Bow River downstream from the Nose Creek confluence, since this plant can produce dense mats that exclude willow and poplar recruitment. We observed seedling colonization of all species across various surface sediment textures, including very coarse gravels and cobbles. The colonization zones were coordinated with elevations and inundation patterns, and this provided the basis for our predictive mapping of future zones with different riparian vegetation types.

Our mapping emphasized four locations of particular concern. The large island and bar upstream from Crowchild Trail was expanded and elevated with the 2013 flood and we anticipate that this will develop into a complex of woodland and shrub patches that will be much more extensive than prior to 2013. We conclude that the island at the 10th St. Bridge may represent a particular challenge. We predict major expansion in the woodland and shrubland, which could block flow through one of the bridge spans, similar to current situation at the Mission Bridge on the Elbow River. We anticipate the development of a substantial woodland grove on the elevated bar near the Centre St. Bridge. While this will probably be primarily downstream from the bridge span, there could still be erosion or flood risk. Finally, Carburn Park Island is an artificial river feature that arose from the flood capture of a prior excavated pond. This island is being densely colonized by reed canarygrass and other weeds and could provide an environmental liability due to this proliferation of problem plants.

Our analyses emphasized locations of potential problems due to hindered river flows or weed encroachment, but these methods would be equally applicable for a complementary application, recognizing locations where the 2013 flood could allow for rejuvenation of riparian woodlands along the Bow River, which had become decrepit after the extensive flood-free interval.

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Introduction and Objectives

Floods and the Floodplain Forest through Calgary

River valley floodplains represent interface zones between water and land. These support rich and diverse riparian, or streamside, ecosystems and often riparian woodlands, vegetation communities dominated by woody shrubs and trees. These riparian woodlands provide rich habitat for birds and terrestrial wildlife and are also favored for human uses, including recreation. With the shade and shelter, abundant wildlife and proximity to water, riparian woodlands were primary zones for initial settlement throughout western North America, and worldwide.

This was the case in southern Alberta as the original forts were situated in river valleys, and often in floodplain zones. Fort Calgary was typical, and established by the North-West Mounted Police in 1875 along the Bow River, at the outflow of the Elbow River. Following the arrival of the railway in 1883 the town of Calgary grew around the 'Bow Fort'. Over a century, Calgary has grown to more than 1 million residents, with the skyscrapers of the city centre only slightly further away from and higher above the Bow River than the original Fort.

Floodplains are relatively flat, low-lying riparian zones that are, as the name indicates, occasionally flooded. Major floods inundated the original settlement of Calgary in 1879 (Figure 1), when Fort Calgary provided the only substantial permanent structure; and again in 1897, flooding the Inglewood area and other areas of settlement and prompting some early settlers to relocate to higher positions within Calgary (Sanders 2013). Only five years later, another major flood in 1902 caused further damage, including the bridge over the Bow River where the 10^{th} St. or Hillhurst Louise Bridge is now situated.

Other floods in the early twentieth-century followed and with the hydrometric gauge installed around 1911, the magnitudes of these floods were determined (Figure 1). The next flood occurred in 1915 and destroyed the original Centre St. Bridge, and subsequently the 1929 flood damaged the newly opened Calgary Zoo (Sanders 2013). The final historic flood of the twentieth century was in 1932. That occurred right after completion of the Glenmore Dam and that empty reservoir trapped the Elbow River peak, attenuating flooding of the Bow River downstream of that outflow.

After 1932, there was a prolonged interval without substantial floods through Calgary. This was partly due to the flood flow attenuation from a sequence of a dozen hydroelectric dams and reservoirs upstream along the Bow and its Rocky Mountain tributaries but probably primarily due to a benign interval, without major flooding in most of the Bow River Basin (Rood et al. 1999). Conversely, within the southern zone of the Bow Basin, major floods occurred periodically through the twentieth century, especially along the Highwood River (Rood et al. 1999).

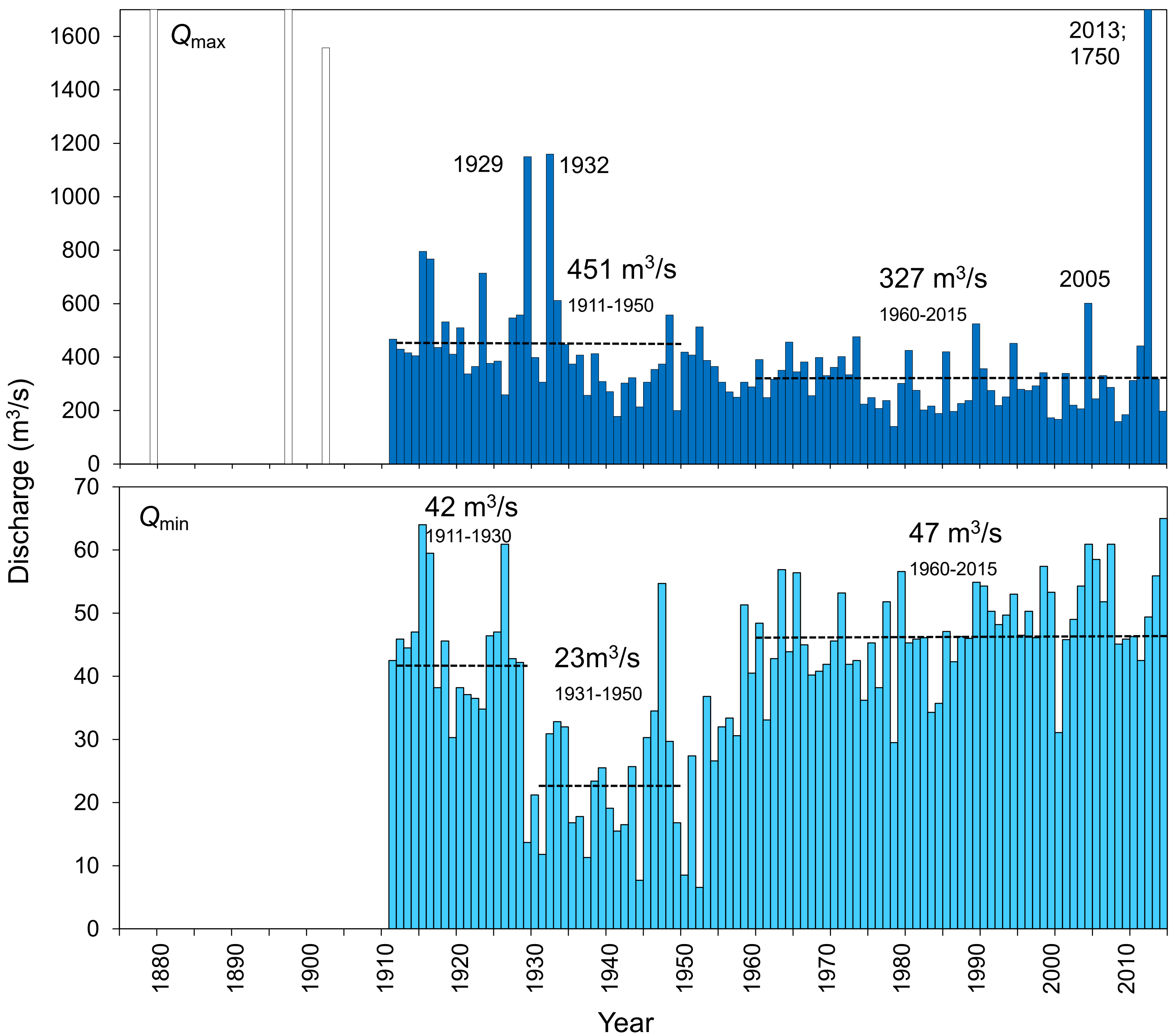


Figure 1. Maximum (Q_{max}) and minimum (Q_{min}) mean daily discharges along the Bow River through Calgary for the period of record. Note the differences in y-axis scales. Mean values for management intervals are provided. Early floods are indicated but were not gauged and should be considered as coarse estimates.

During the eight-decade interval without a major flood, there was progressive development along the Bow River through Calgary and this included the construction of many more bridges. Each was associated with bank armoring with rip-rap boulders or other bank stabilization structures. There was also progressive bank stabilization in between the bridges along the Bow River and also along the Elbow River valley below Glenmore Dam.

The combination of the lack of natural floods and the extensive development and bank stabilization resulted in a static configuration of the riparian woodlands that are predominantly balsam poplar, *Populus balsamifera*. This decrepit condition was recognized particularly by Gary Szabo and other biologists with Trout Unlimited Canada, who were familiar with the essential role of riparian woodlands in providing leaf and branch litter that contributes to the aquatic food web, and were also very familiar with the Bow River. Following that concern, we undertook initial inventories of the riparian woodlands along the Bow River primarily from Calgary to the Carseland weir and observed a lack of juvenile poplars along the Bow River upstream from the outflow of the Highwood River, in contrast to the reproducing population downstream (Rood and Bradley 1993). This indicated that the static riparian woodland was due to the lack of recruitment with major floods, while the flood contributions supported the essential physical disturbance and reproduction downstream of the Highwood River (Rood et al. 1999).

Approaching the end of the twentieth century, major floods occurred in the South Saskatchewan Basin (SSRB) in 1995 and 2005. The 1995 floods were centered in the Oldman River Basin, as the Oldman River flow through Lethbridge reached the highest peak of the century-long record, thus providing the ‘flood of the century’ (Rood et al. 1998). This event was notable relative to instream flow regulation and riparian woodlands since, for the first time in Canada, there was some intent to operate dams to provide ramping, gradual post-flood recession, which was intended to mimic the natural post-flood pattern and encourage the seedling recruitment of riparian cottonwoods and willows (Rood et al. 1998). Ramping was also implemented in the subsequent high-flow years of 1996 and 1997 and this multiple-year sequence succeeded in producing a prolific colonization event, which contrasted to the deficiency of cottonwood colonization after prior flood years in the Oldman River Basin (Rood et al. 1995).

Major flooding in 1995 also occurred along the southern tributaries of the Bow River Basin, and especially along the flood-prone Highwood River. That flood event caused substantial damage through the town of High River, and the positioning of that town is unfortunate relative to flood vulnerability, since it is situated in a low-lying position where the Highwood River naturally overflows its banks, with some of the flood water subsequently flowing into the Little Bow River, which naturally originates right in the location of the town of High River.

The Highwood River flood was important for the Bow River system since it provided physical geomorphic disturbance that created, scoured and expanded gravel bars and islands. These barren surfaces were subsequently available for colonization by riparian vegetation and especially balsam poplars, the predominant tree and the ecological foundation for the riparian woodlands. At some sites there was prolific poplar colonization after 1995 and these young trees grew and matured over the subsequent decade.

This process along the Bow River downstream of the Highwood River outflow following the 1995 flood is relevant to the current consideration of the Bow River through Calgary. It provides an indication of the likely future condition of growing riparian woodlands on some of the newly colonized gravel bars and islands, which were assessed in 2015, during the third riparian plant growth season after the major flood of June, 2013.

As a clarification, in this report, ‘gravel bars’ will be used inclusively to refer to the alluvial depositional features that often include surface gravels, cobbles and interstitial sands. Along the Bow River, some bars are predominantly covered with cobbles, as characterized by their particle sizes that are larger than gravels, but these will still be referred to as ‘gravel bars’. We provide information about surface sediment textures (particle sizes) and consider influences on vegetation establishment.

Another major flood in the SSRB occurred in 2005, and this followed another exceptionally heavy rain event, but this was situated substantially north of the 1995 rains. The 2005 floods occurred especially along the Red Deer River and its tributaries, including extreme flows along the Little Red Deer River. The rains extended to the Bow River Basin and there was slight flooding along the Bow River and, again, more severe flooding along the Highwood River through the Town of High River.

The 2005 flood removed some of the decade-old juvenile balsam poplars along the Bow River that had established after the 1995 flood. Conversely, in many locations, the decade-old trees were sufficiently large to withstand the 2005 flood. This is also instructive relative to the 2013 flood of the Bow through Calgary and suggests that the key interval for riparian colonization may extend for a decade after the major flood event.

The knowledge gained from the 1995 and 2005 floods within the SSRB, combined with knowledge gained from riparian woodlands dominated by cottonwoods, riparian poplars, elsewhere around the Northern Hemisphere provides a reasonable foundation for the study of riparian colonization and succession along the Bow River through Calgary, following the 2013 flood. This collective information may even be sufficient basis for predictive mapping of riparian vegetation colonization and survival. This was the major intent of this study, to investigate and characterize the colonization of riparian vegetation on the newly formed, expanded and/or scoured gravel bars and islands along the Bow River through Calgary, following the exceptional, 2013 flood.

This knowledge is somewhat descriptive, characterizing ‘what’ grows ‘where’, particularly in relation to hydrogeomorphic surfaces, and the field observations are intended to provide validation and calibration of aspects such as elevations relative to the water surface and also interacting influences including the sediment texture, the size distribution of the alluvial particles - sands, gravels and cobbles.

This knowledge could subsequently be used for two opposing objectives. Through the densely developed urban corridor, the priority relative to river and riparian management is to minimize overbank flooding and subsequent inundation and damage along the river corridor and through the urban zones. We were especially attentive to locations in which riparian woodland groves could impede river water conveyance and thus elevate stages and subsequently exaggerate over-bank flooding. Candidate locations were identified in the prior stages of the Calgary Rivers Morphology project and were often associated with bridges.

The opposing objective would be to use the knowledge to encourage or promote riparian woodland colonization in locations where there is little risk to infrastructure or urban or suburban developments. Thus, in locations where there is 'room for the river', the 2013 flood provides an important opportunity for riparian rejuvenation. The achievement of these opportunities may benefit from knowledge relative to locations that are more or less vulnerable to weed invasion versus the proliferation of the favored native vegetation.

These two opposing objectives: (1) limiting woodland development that could increase flood hazard, versus (2) promoting woodland development in suitable locations, would both benefit from the same mechanistic understanding of the physical environmental conditions and biological factors that influence the colonization and succession of riparian vegetation. Thus, this study component sought to characterize the nature of colonization by riparian vegetation on the newly formed or expanded gravel bars and islands along the Bow River through Calgary and to use this information to provide predictive mapping of the likely riparian woodland colonization and succession at these locations and by extension, at other locations along the Bow River through Calgary.

Study Approach

Our study involved overlapping analyzes of four components: (1) historic and recent river flow patterns; (2) field distributions of riparian vegetation on the bars and islands; (3) patterns of bar and island inundation with different river flows during the interval after 2013, based on geo-rectified aerial photographs posted on Google Earth; and (4) the coordination of the hydrologic, vegetation and aerial photographs to provide maps that forecast vegetation types and distributions on particular islands and bars that are regarded as potentially impeding river conveyance and consequently increasing the flood hazard risk.

Our use of the Google Earth maps (i.e. georectified aerial photographs) are within the approved Google Permissions and we generally provide attribution in our figures (https://www.google.com/permissions/geoguidelines.html). The exception is for maps that were imported into Arc-GIS for plotting of the transect and quadrat positions, and then used for the composite 'camo-maps' ('camouflage maps'). We thus hereby recognize this scientific application of the Google Earth maps.

Hydrology

River discharges (*Q*, in m^3/s = cubic meters per second) were obtained from the web-based 'HYDAT' database of Environment Canada's Water Survey of Canada. To complete these mean daily *Q*, we also obtained provisional data from Dr. John Mahoney of Alberta Environment and Parks (AEP), which included stage or discharge values at 15 minute intervals, for the summer season of 2015. These shorter-term values were used to estimate the *Q* during the field site visits.

We emphasized data from the 'Bow River at Calgary', (05BH004) and we regenerated a discharge-stage rating curve based on the daily values from 2012 through 2014. With the change in channel geometry, the rating curve had been refined annually but we derived a general equation over the study interval and this would provide sufficient precision for the field coordination and mapping. This best-fit equation was:

$$\text{Stage} = 0.461 \times \ln(Q) - 0.818;\ R^2 = 0.973$$

Stage was in m and *Q* (Discharge) was in m^3/s and the R^2 indicates 97% correspondence.

For sites below the Elbow River, we added the discharges from the Elbow River below Glenmore Dam (05BJ001) to the Bow River at Calgary values to estimate the combined *Q*, and recognize that this neglects the minor contribution from Nose Creek and urban drains, or for the Hull's Woodland site the more substantial contribution from Fish Creek and withdrawals at the Calgary weir. This approach was not intended to precisely determine the river *Q* at each site but instead was used to coordinate the field data, flow recurrences and the reported gauge *Q* at the times of the various aerial photographs.

To provide a consistent reference relative to the elevations, we provide adjustments to compensate for the river stages during the field visits. For riparian vegetation analyses, the base stage is commonly used and we regarded this as the stage associated with the typical minimal flow during the plant growth season. For the Bow River, the growth season was regarded as May through October and we thus considered the minimal daily *Q* for each year of record during this seasonal interval. With damming and flow regulation, late summer flows are generally augmented along the Bow River through Calgary and consequently the minimal flows have been elevated after the 1954 completion of Bearspaw Dam, the final structure in the Bow River system (Figure 1).

Subsequently, we set the base stage as associated with 47 m^3/s, the mean yearly minimum daily *Q* for the plant growth interval from May through October from 1960 through to 2015 (Figure 1). This is associated with a value of 1.0 m for the Bow River hydrometric gauge and we set this as the base stage, or elevation '0'.

Our field surveys occurred with fairly low river discharges of 70 to 80 m^3/s and the associated stage would be about 0.2 m above the base stage; we thus provide this offset in the elevation plots. For river and riparian research there is a challenge in that hydrometric gauges are typically positioned at bridges and these are commonly constricted positions with steeper stage versus discharge functions than for most typical positions along a river reach. Since our field work was during low flows, this confounding influence would be relatively minor. Further, since our ultimate mapping was based on the actual river shoreline positions at various discharges, the localized variation in the stage versus discharge function would be incorporated.

These and other imprecisions existed but we consider that the magnitude of error in elevations from these factors would be lower than the imprecision of the field elevation assessments and by the inherent breadth in the range of hydrogeomorphic requirement for colonization of the different riparian plant species. While our surveys provided elevations to $\pm$1 cm the positioning of the staff gauge on or off of a large gravel or cobble particle would commonly introduce differences of 2 to 5 cm or more, and there are also other irregularities of the bar and island surfaces. Additionally, while the river is progressively sloping downwards downstream, there are irregularities such as riffles versus pools that introduce further variations. We sought to optimize precision as was feasible and anticipate that our ultimate accuracy would be to around $\pm$5 cm relative to the adjacent river water surfaces. We consider that this resolution should be quite sufficient for the vegetation analyses and ultimately for the predictive vegetation mapping.

However, there was a further complexity that could have introduced variation exceeding our 5 cm objective. There was substantial short-term variation in Q that occurred through much of the summer of 2015 (Figure 2). The arrow indicates a spike in flow ranging from 60 to 90 m^3/s. We considered the reported Q during our field work and this was generally between 70 and 80 m^3/s. We did not observe substantial river stage change during any site visit and are optimistic that the flow and stage pulses would not substantially impact our analyses of river-coordinated elevations. Supporting this, the correspondence between our observed elevational distributions of the vegetation and the shoreline inundation patterns suggests that the flow irregularity did not impede the project success. This short-term flow variation thus provided another complexity, but we anticipate that the field measurements at multiple sites and over multiple days would have dampened this confounding influence.

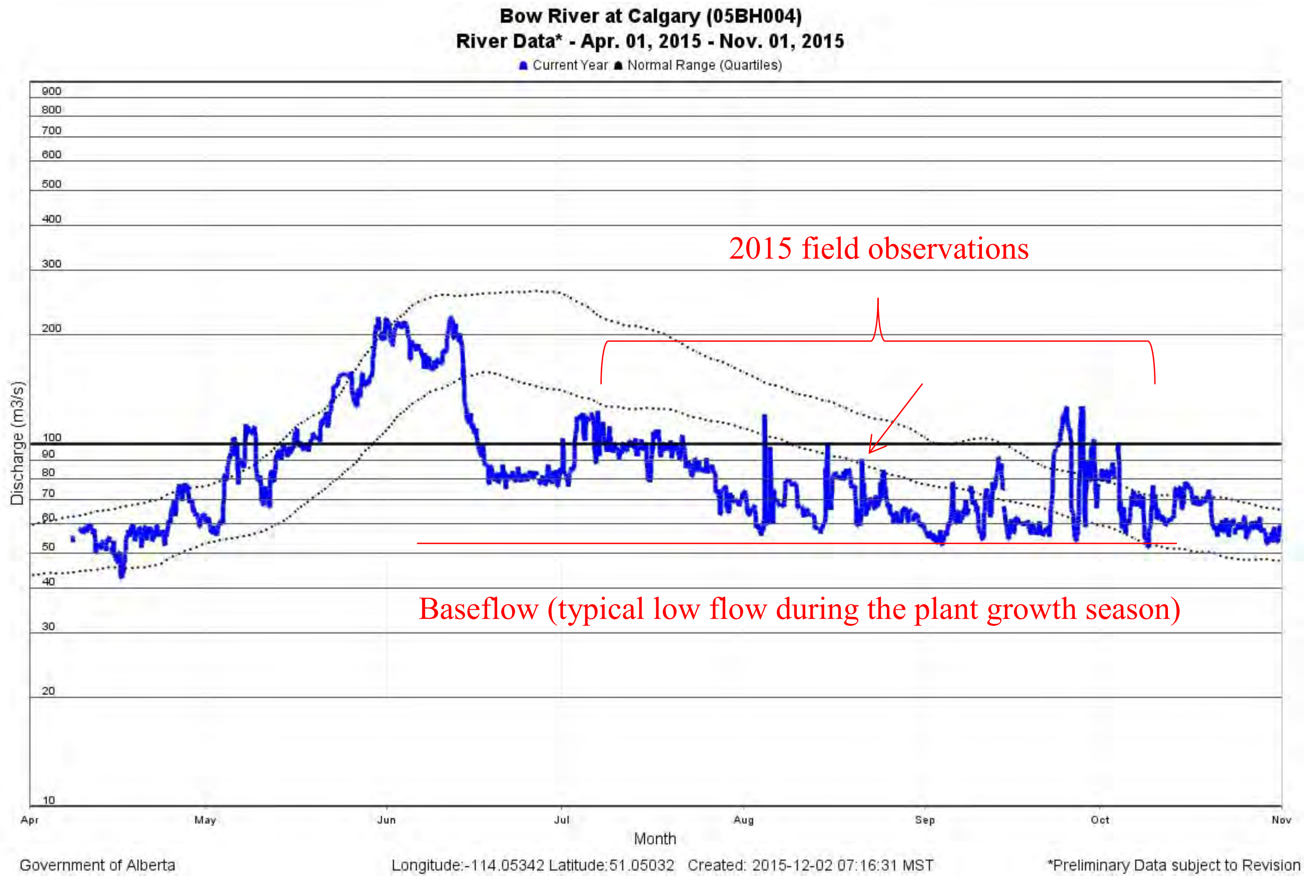


Figure 2. The seasonal hydrograph with provisional discharges for the Bow River at Calgary through 2015. The interval of field observations is indicated. An arrow indicates the field survey interval and the confounding influence from a flow spike. Note that the baseflow has been augmented following river damming and flow regulation.

Field Study - Riparian Inventory

The intent of the field work was to characterize the riparian vegetation on the newly formed or expanded gravel bars and islands. The emphasis was on new seedlings that had colonized the newly deposited or scoured barren surfaces and for reference we also tied in the distributions and elevations of some previously established vegetation.

We undertook elevational surveys of each bar or island, with combinations of transects, additional survey placements and surveys of all of the quadrat positions (Figures 3 and 4). Along the transects, we surveyed elevations at ~ 2 m intervals for short (~ < 25 m) transects, or at ~ 5 m intervals, or at surface transitions for longer transects. We surveyed additional positions on the bar or island surfaces to capture the apparent surface character, and along the edges of the island or bar, to plot the adjacent, sloping river water surfaces. These surveyed values provided reference elevations that were then coordinated with the shoreline positions at different river flows, which progressively inundated the bars or islands, and were displayed in the numerous aerial photographs that are archived in Google Earth.

Survey was with a Uranus Automatic Level (Tianjin, China), consisting of a leveling telescope with a cross-hair target, mounted on a rotating base, with compass calibration for bearings. Staff gauges could generally be read to ±1 cm and for short distances (~ < 50 m), positions were determined with a fiber tape laid along the transect and read to ±0.1 m. For longer distances (~ > 50 m) a laser rangefinder was often used (±1 m; Bushnell Yardage Pro400, Kansas, US) (Figure 3). Thus, we sought higher precision for the elevations (as indicated in the Hydrology section, ±5 cm), while our spatial positioning would be accurate to about ±1 m.

Vegetation was assessed within quadrats that were haphazardly positioned to cover the representative range of surface elevations and vegetation occurrences (Figure 3). Following a fairly random walk, the quadrat was positioned and all plants within the 1x1 m quadrat were identified and counted. The position of each quadrat was determined with WAAS-corrected GPS (Garmin eTrex 30) and the elevation of each quadrat was determined by survey.

Balsam poplar seedlings were common and these were counted by size classes that were coordinated with ages and years of establishment: 2015 (0-10 cm tall), 2014 (10-30 cm), 2013 and older (> 30 cm). Our initial categorization followed uprooting of some seedlings and observation including stem bud scars, but these age distributions are approximations. For seedlings established in 2013 or 2014, the heights of the tallest three balsam poplar seedlings were measured.

To complement the quadrat surveys, we also overviewed the bar or island and recorded notes about other plant occurrences and other surface features and apparent impacts.

'Rovers' with staff gauges stopped at intervals along transects and also at other positions on the bars and islands, and elevations were determined relative to adjacent river surfaces. Positions were determined with bearings from the transit, and distances with tape measure or a laser range finder.

Vegetation was inventoried in 1 x 1 m quadrats, with strings at 0.25 m intervals. Sediment sizes were assessed at each string intersection (3 x 3 per quadrat). All plants within the quadrat were counted by species. For balsam poplars, apparent seedling ages were assessed based on sizes.

The elevation of each quadrat was surveyed.

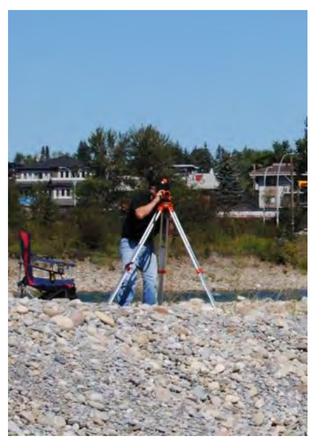


Figure 3. Photographs of field inventory methods.

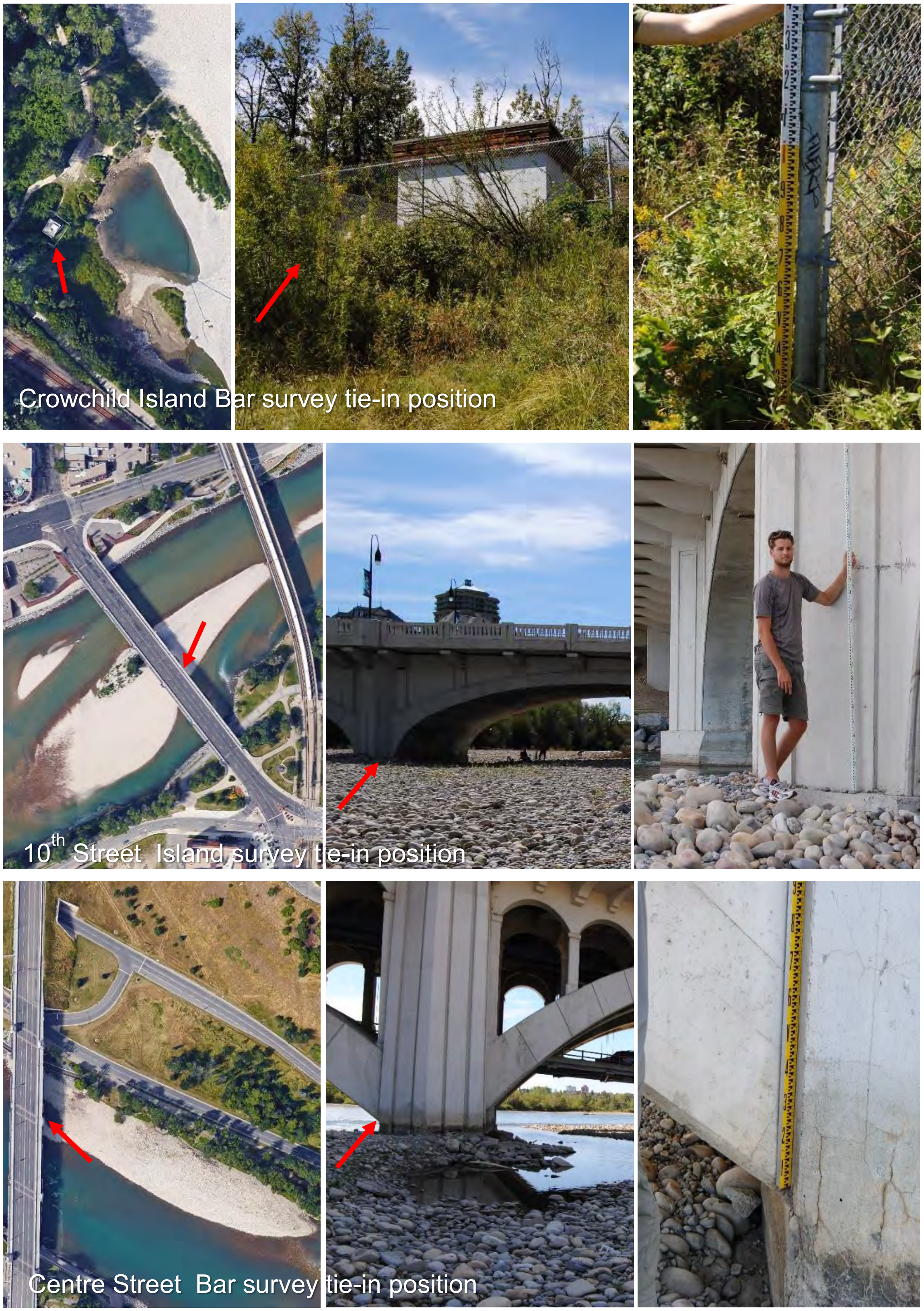


Figure 4. Reference tie-in photos for elevational surveys.

Field Observations at Twelve Study Sites

Following from the *Calgary Rivers Morphology Project* workshop in July, 2015, we chose twelve study sites to investigate (Figure 5; Table 1). These included prospective hazard locations relative to riparian woodland development that could impede river conveyance and thus elevate future flood stages through the City of Calgary. The sites were also chosen to represent the range of hydrogeomorphic conditions, the combination of: (1) physical forms including islands, lateral bars and meander lobe point bars, (2) different elevations above the river and (3) different surface conditions relative to topographic variation and surface sediment types.

We visited each site and observed conditions and took representative photographs. For eight of these sites, we surveyed elevations and for seven sites we established quadrats to inventory colonizing seedlings and we also undertook Wolman pebble counts (Table 1). We display the positions of the transects and quadrats on aerial photographs of the sites and for this reference, we selected the current (Dec. 2015) Google Earth terrain mosaic associated with the 3-D simulation in Google Earth. Google Earth provides an extraordinary and public image library and this is available for academic and scientific study, and in accordance with Google Earth terms, to acknowledge the open resource we display the trademark logo.

For recent historic analysis, we assessed aerial photographs that were posted on Google Earth, with the ‘clock’ feature to sort through the many sequential images, which had been georectified and spatially coordinated. This resource was much more extensive than we had expected, with around 40 post-flood aerial photographs for most locations along the Bow River through Calgary.

We viewed these sequences and for each study site we present sequences to display the physical planform changes and vegetation alterations. We generally commence with a view of each study site from the summer or autumn of 2012, to display the pre-flood configuration of the bar or island, and the apparent pre-flood vegetation. We next sought aerial photographs during the flood and the best view was generally from June 25, 2013. This would have been four days after the flood crest and there would thus have been substantial river stage recession. The flooded areas would generally have still had standing or flowing water but there would have been some post-flood exposure of the higher bar or island zones and reduced inundation of vegetation. We then provide one or more post-flood aerial photographs of each site and often select the image from August 22, 2015. This sequence provided fairly sharp resolution and was in the interval of our field surveys that were primarily undertaken on August 19 and 25, 2015.

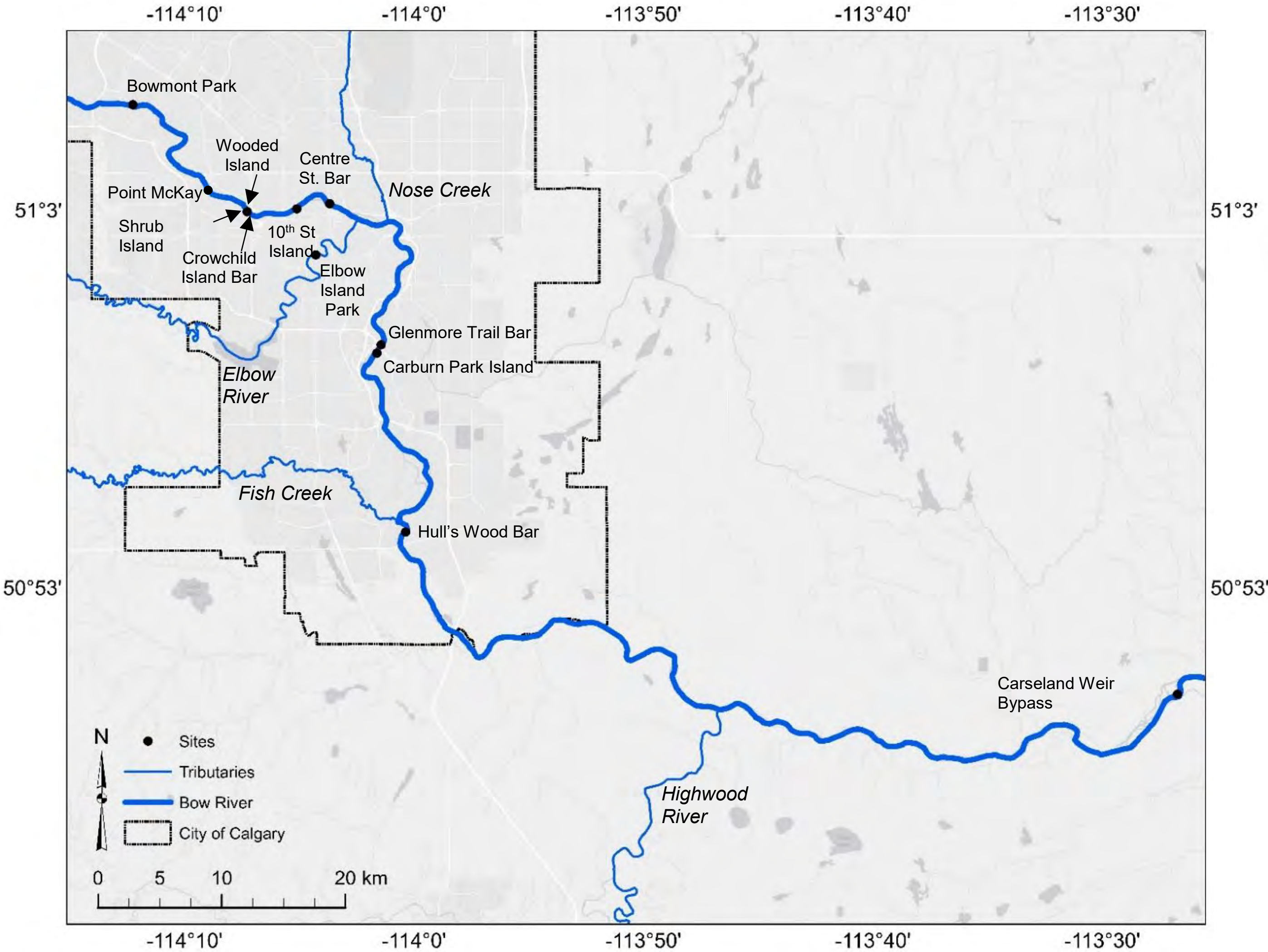


Figure 5. Map of study site locations along the Bow River through Calgary. This map was created in ArcMap 10.0 with rivers data from AltaLIS, from Alberta hydrology and provided under the open data licence.

Table 1. Study site locations along the Bow River and activities undertaken. River distances are upstream from the Highwood River inflow and compared to the distances used in the morphology study.

Study Site		River Distance (km)	Location		Studies undertaken				
			Latitude (N)	Longitude (W)	Vegetation Observation	Elevation Survey	Seedling Inventory	Pebble Count	Inundation Analysis
1	Bowmont Park (BMP)	63.8	51° 05'55"	114° 12'15"	√	-	-	-	-
2	Shrub Island (SI)*	54.1	51° 03'09"	114° 07'26"	√	√	√	√	-
3	Wooded Island (WI)	53.9	51° 03'04"	114° 07'17"	√	-	-	-	-
4	Crowchild Island Bar (CIB)*	53.6	51° 02'56"	114° 07'16"	√	√	√	√	√
5	Bar Above 10th St. (BAT)	51.5	51° 02'58"	114° 05'27"	√	√	-	-	-
6	10th St. Island (TSI)*	51.0	51° 03'01"	114° 05'06"	√	√	√	√	√
7	Centre St. Bar (CSB)*	48.9	51° 03'10"	114° 03'40"	√	√	√	√	√
8	Glenmore Trail Bar (GTB)*	37.2	50° 59'15"	114° 01'26"	√	√	√	√	-
9	Carburn Park Island (CPI)*	36.8	50° 59'00"	114° 01'37"	√	√	√	√	√
10	Hull's Wood Bar (HWB)*	24.3	50° 54'02"	114° 00'22"	√	√	√	√	-
11	Carseland Weir Bypass (CWB)		50° 49'30"	113° 26'43"	√	-	-	-	-
12	Elbow Island Park (EIP)		51° 01'44"	114° 04'16"	√	-	-	-	-

*primary study sites

Table 2. Observations of study sites along the Bow River.

Study Site		Dates - all included observations and photographs and inventory dates are indicated along with (personnel)
1	Bowmont Park (BMP)	Sept. 22, 2015
2	Shrub Island (SI)*	Aug. 19, 2015 inventory (SK, KN, LP, SW)
3	Wooded Island (WI)	Aug. 19, 2015 (SK, KN, LP, SW)
4	Crowchild Island Bar (CIB)*	July 12, 2015; Aug. 19, 2015 inventory (SK, KN, LP, SW)
5	Bar Above 10th St. (BAT)	July 12, 2015; Aug. 19, 2015 (SK, KN, LP, SW)
6	10th St. Island (TSI)*	July 12, 2015; Aug. 19, 2015 inventory (SK, KN, LP, SW); Sept.15, 2015
7	Centre St. Bar (CSB)*	July 12, 2015; Aug. 19, 2015 inventory (SK, KN, LP, SW)
8	Glenmore Trail Bar (GTB)*	Aug. 25, 2015 inventory (SK); Oct. 11, 2015 (DF)
9	Carburn Park Island (CPI)*	Aug. 25, 2015 inventory (SK); Oct. 11, 2015 (DF)
10	Hull's Wood Bar (HWB)*	Aug. 22, 2013; May 20, 2014; June 20, 2014; June 26, 2014; Aug. 11, 2014; Aug. 25, 2015 inventory (SK)
11	Carseland Weir Bypass (CWB)	Sept. 15, 2015
12	Elbow Island Park (EIP)	Sept. 15, 2015; Oct. 10, 2015 (DF)

*primary study sites

All visits included Stewart Rood, and additional researchers were: DI, Dianne Fitzgerald; SK, Soba Kaluthota; KN, Kayleigh Nielson; LP, Laurens Philipsen; SW, Sam Woodman

1. Bowmont Park (BMP)

Situated in northwest Calgary along the north (river left) bank of the Bow River, Bowmont Park is a popular regional park and one of the City's larger Natural Environment Parks (Figure 6, 7 and 8). In the Calgary Rivers Morphology Project concern was expressed for bank erosion along the south (river right) bank, opposite the Park area. The south bank provides a steep cut-bank, with housing along the top and in some places homes or other buildings are situated quite close to the steep bank.

Bowmont Park was the first study site downstream from Bearspaw Dam and that structure would impact not only the water flow regime, but also the sediment regime. Suspended sediments would settle in the slack water of the upstream reservoirs and finally in Bearspaw Reservoir. Consequently, sediment-impoverished 'hungry water' would be released from the dam and this clear water would erode, suspend and transport the sands and gravels that had been deposited prior to the dam's implementation. As a consequence, this river reach would be coarsening, as the finer sediments are progressively exported and not replenished, while the larger cobbles would be more resistant to erosion and transport.

Downstream from the outflow, Valley Ridge Golf Course extends along the south (right) bank and there may be some concern for localized erosion. Golf courses, however, can probably be realigned more readily than developments with streamside buildings. Downstream, the river turns left with a high, densely wooded bank above the turn. The woodland density and condition indicates limited erosion or bank slumping in recent decades.

Passing below Stoney Trail, the river passes Bowness Park, where the channel widens and the south bank has a sequence of eight large rock groynes angled upstream into the current. From these, there is extensive and continuous rock armour along the south bank (Figure 8 BP1) to the 85th St. Bridge, which provides the western limit of Bowmont Park. That armored bank resisted the river and the 2013 flood flow provided extensive erosion and deposition on the upstream end of the Bowmont Park island, which supports the railway line. At that upstream zone, the surface material is very coarse, and predominantly cobbles (Figure 8 BP2, BP3). As indicated in the pre-flood, flood, post-flood aerial photograph sequence (Figures 6 and 7), there was substantial thinning of the woodland at the upstream end of the island. Slightly surprisingly, the shrub patch at the extreme upstream end was more resistant to erosion and persisted through the flood. This patch consists of willows (*Salix* species) and especially sandbar willow (*Salix exigua*), and confirms the flood-resistant nature of this shrub. This woody plant is characterized by extensive fine branching, with these thin branches being pliable, and narrow leaves that would minimize drag. This shoot architecture is ideally suited to survive the shear stress of swift water flow with a major flood. We had somewhat anticipated this adaptive benefit (Rood et al. 2011) and the shrub's persistence through the 2013 Bow River flood provides reasonably conclusive direct demonstration.

Bowmont Park
Pre-flood
Sept. 7, 2012

Flood
June 25, 2013

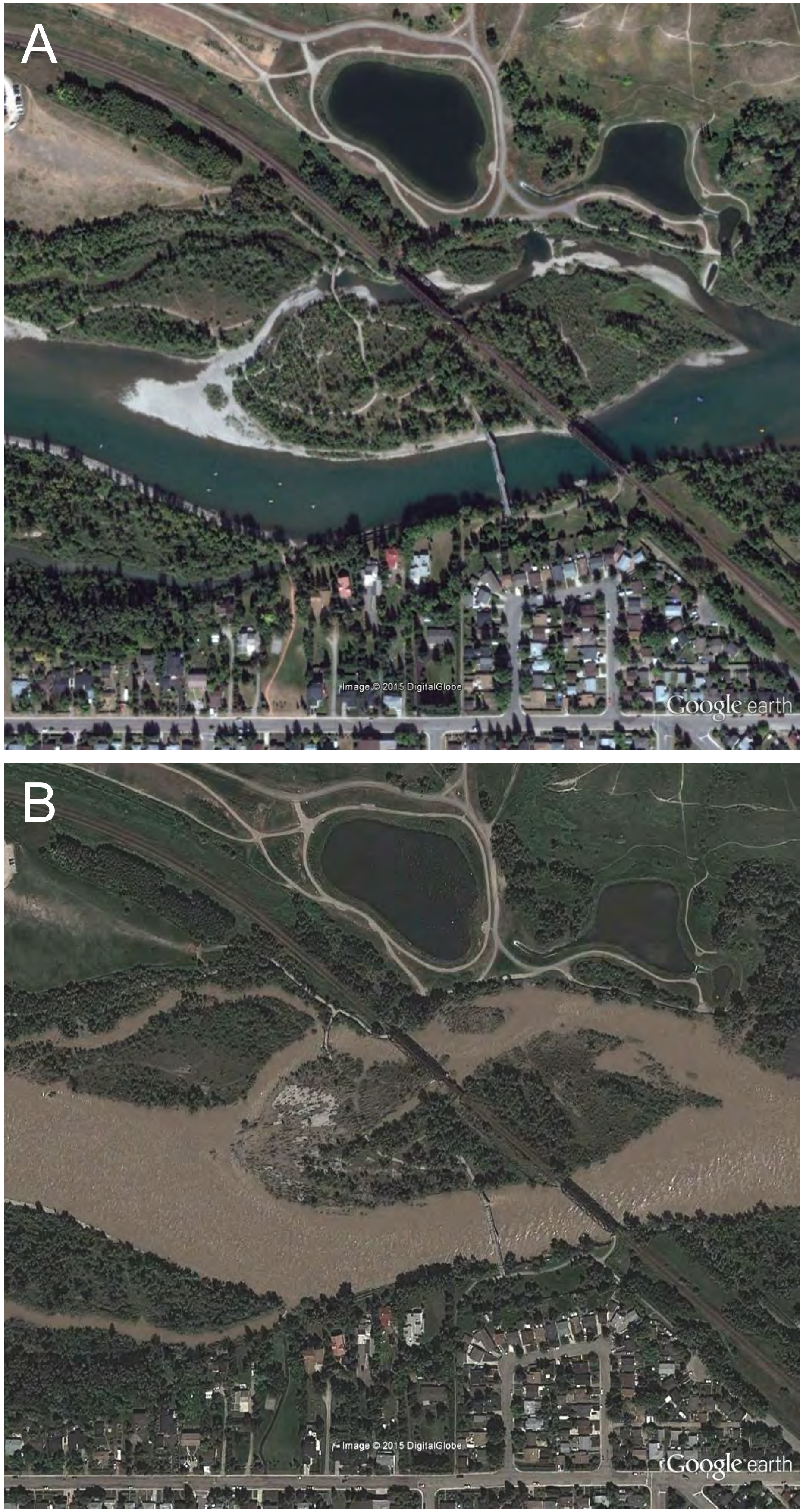


Figure 6. Aerial photographs showing the Bowmont Park study site prior to the 2013 flood (A) and during the flood, but after crest (B).

Figure 7. Aerial photograph showing the Bowmont Park study, Aug. 22, 2015, after the 2013 flood. The numbers indicate positions from which the ground level photographs were taken.

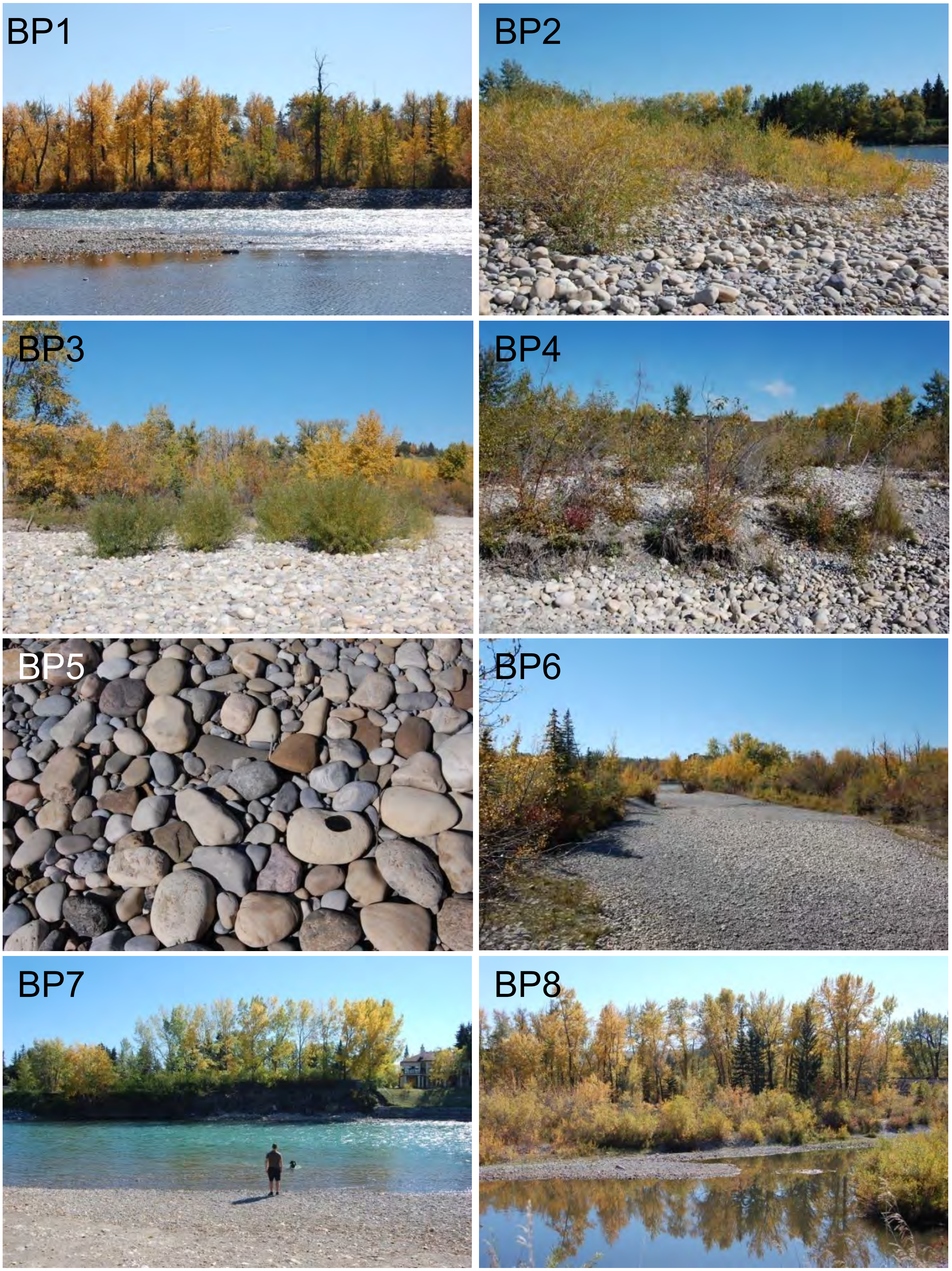


Figure 8. Ground level photographs at the Bowmont Park study site. The photograph numbers correspond to the positions indicated in Figure 7.

In contrast to the flood resilience of the willows and especially sandbar willow, other shrubs on the Bowmont Park Island were toppled, stripped of leaves and uprooted by the flood. As displayed in BP4 (Figure 8), shrub-sized river birch trees and other shrubs, as well as juvenile and even mature balsam poplar trees were more impacted and the substantial gaps in the woodland indicate complete excavation of many of these. The remaining clumps of shrubs have protected some soils, with sands and silts held by the plant root systems and some protection of the surface materials (Figure 8 BP4).

The minor left channel has been scoured and slightly widened but the overall configuration of the island complex remains largely intact, with the most extensive change being the scour of shrubs and sediments at the upstream end of the island. That scoured upstream end and the reactivated left channel have very course sediments (Figure 8 BP5) and there were very few seedlings observed on these surfaces. This thus seems inhospitable for seedling colonization and we might anticipate that instead, there would be clonal expansion especially of the sandbar willows as well as some recovery and expansion of the other surviving shrubs, including the river birch. Over time there would be rather slow redevelopment of the island soil, particularly since there would be very little sediment deposition since the upstream sediment source is limited and the water from Bearspaw Dam would be almost entirely sediment-impoverished. The brown turbidity of the flood photo indicates some silt but the overall sediment regime is almost certainly vastly impacted due to the upstream dams.

At the lower zone along the left channel, the woodland displays more structure, a term for the vertical extent and diversity. There are thus mature balsam poplars and a lower shrub layer with a range of woody plants and fringes of herbaceous plants (Figure 8 BP8). This riparian zone receives outflow from a stormwater wetland system and this would provide water as well as supplemental nutrients, nourishing the vegetation.

<u>1a. Point McKay Bar</u>

Moving downstream there is an island bar adjacent to the Point McKay townhouse complex along the north bank of the Bow River, downstream of Edworthy Park (Figure 9). This shallow bar is predominantly occupied by willows and has been the site of our longer-term riparian willow study (Amlin and Rood 2001). As was observed at the Bowmont Island, the Point McKay willows survived through the 2013 flood, even though this bar is quite low and would have experienced extended inundation and swift flows. This provides a second demonstration of the flood resiliency of willows and especially sandbar willow.

Opposite the lower end of the Point McKay island bar, the south bank of the Bow River has been extensively armored with bank boulders and for an extended interval. Here, the Canadian Pacific Railway (CPR) line flanks the river and is restricted to the narrow band below the high and steep north-facing bank, which is forested with Douglas fir (*Pseudotsuga menziesii*), and where the Douglas Fir Trail ascends the hill to a valley overlook. Extending downstream, there is a major change in the river and valley configuration as the river swings away from the right bank and there is an extensive lower bench that extends downstream almost to Crowchild Trail. The lower end of this zone provided our next three study sites.

Figure 9. A post-flood composite aerial photograph of the Point McKay bar (Aug. 22, 2015), which has provided a longer-term study site for riparian shrubs and particularly willows along the Bow River.

2. Shrub Island (SI)* (* indicates a primary study site)

Two adjacent islands, Shrub Island and Wooded Island, were selected to represent the variation in island elevations, and correspondingly, the extents of flood inundation and scour. Prior to the 2013 flood, both islands were almost completely covered with vegetation (Figure 10, SI-a). However, as suggested by our naming, Shrub Island was occupied by shrubs, shorter woody plants, while Wooded Island had extensive shrubs as well as trees, with their taller stature indicated with the shadows in the pre-flood aerial photograph, and their presence confirmed with the field visit.

The upstream island, Shrub Island, is a low island that was entirely inundated with the 2013 flood (SI-b). After the flood much of the island was barren, indicating that the flood scoured away much of the vegetation (SI-c). The aerial photographs indicated that some vegetation remained, somewhat surprisingly, primarily at the upstream end of the island (Figure 11).

The field visit on Aug. 19, 2015, revealed that the remaining shrubs were almost entirely willows, and primarily sandbar willows (Figure 12 SI1 and SI2). This is consistent with the upstream observations that sandbar willow was uniquely capable of withstanding the major flood flows. These surviving willows were commonly 1 to 1.2 m tall and appeared healthy, suggesting relatively complete rebound after the flood. Thus, sandbar willow is exceptionally flood-resilient. With the thin, pliable stems, we would anticipate that this shrub would be readily bent over by the swift-flowing water, and with the narrow leaves there would be minimal leaf stripping from the shear stress. Thus after the flood receded, this shrub would rebound with minimal damage.

The surface of Shrub Island involved three categories of alluvial sediments. There were common large cobbles or small boulders that were scattered over the surface. There were also much smaller sediments, with large gravels and then a gap in the size distribution with fewer small gravels but abundant sands that were both sifted into the gaps between the larger sediments and also provided some sandy surface exposures (Figure 12 SI1). We established transects, as shown in Figure 11, and haphazardly positioned quadrats for measurements of the sediments and inventory of vegetation.

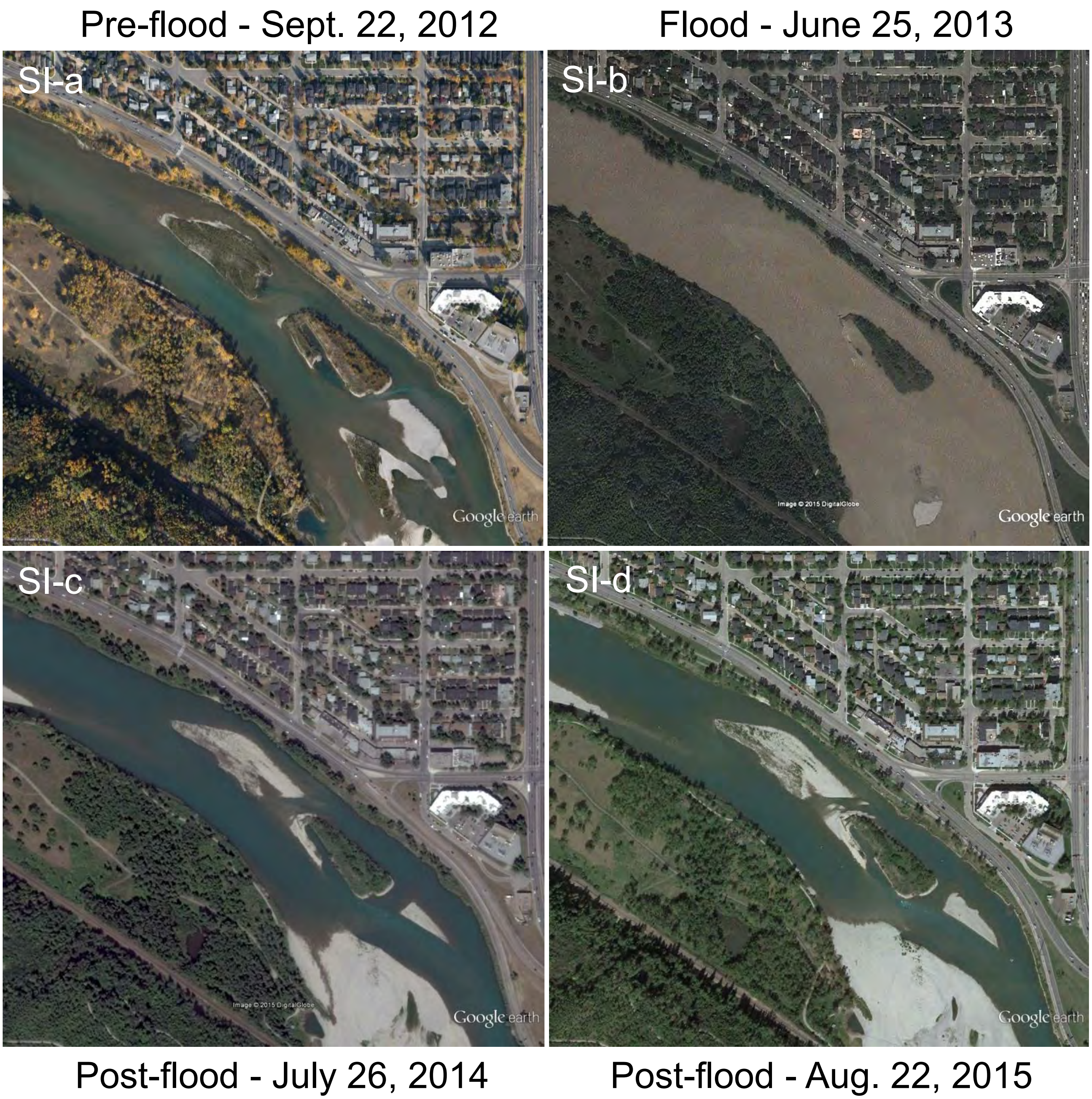


Figure 10. Aerial photographs of the Shrub Island and Wooded Island study sites in the Bow River displaying conditions prior to the 2013 flood (SI-a), during the flood, and after the flood in 2014 and in 2015 at about the time of the field sampling.

Figure 11. A post-flood aerial photograph of Shrub Island in the Bow River showing the study transects and quadrat locations.

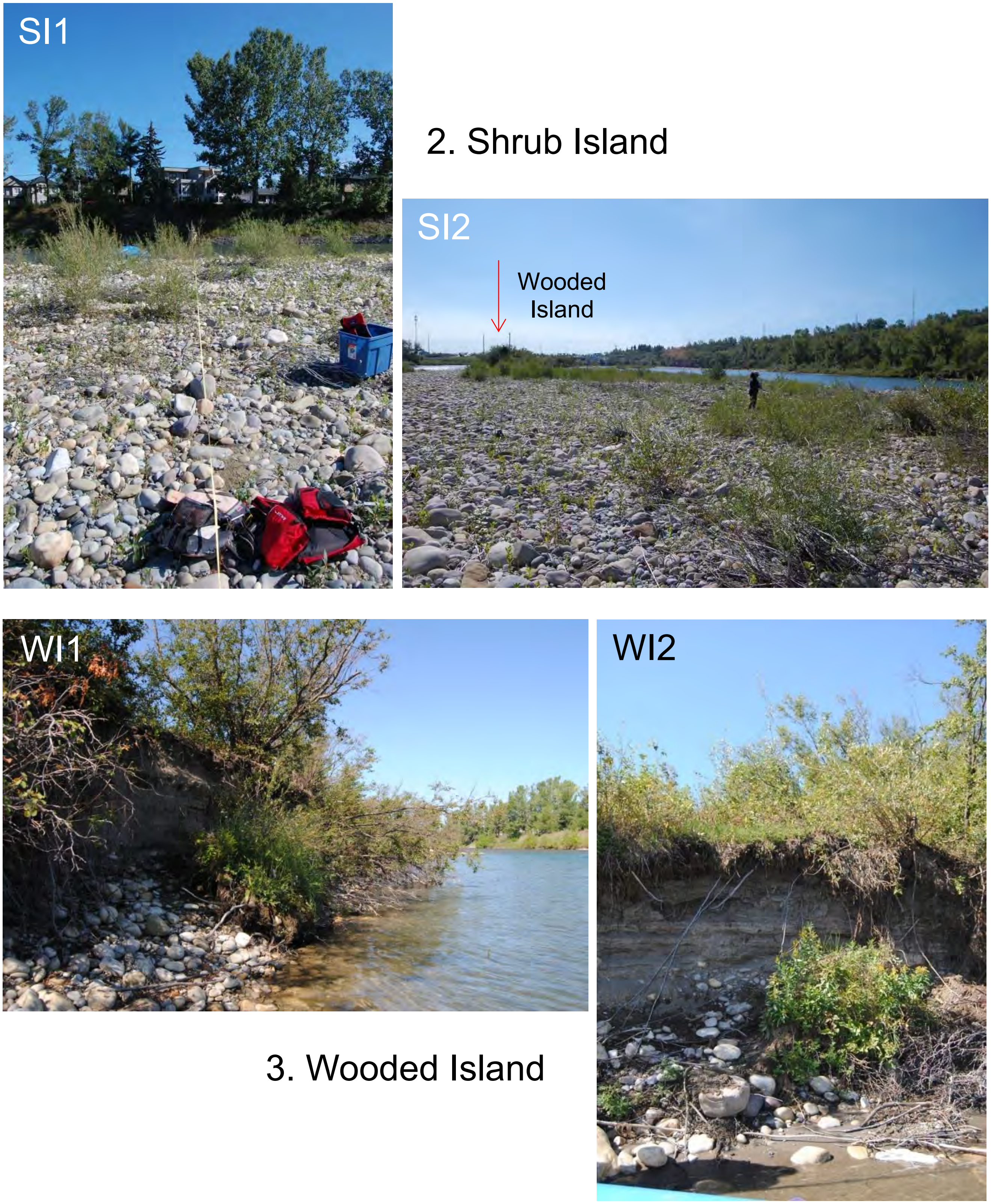


Figure 12. Ground level photographs at the Shrub Island and Wooded Island study sites.

We observed seedlings of 15 plant species in the quadrats (Table 3) and their elevational distributions were also coordinated with inundation patterns displayed in post-flood aerial photographs with different river flows (Figure 13). At this site the seedlings were predominantly woody plants, with balsam poplar seedlings occurring in all 9 quadrats, with a mean density of ~ $21/m^2$ (Table 4). Chokecherry seedlings were also abundant, occurring in all but one quadrat, while sandbar willow and Manitoba maple seedlings were less abundant. We observed two Jackii poplar (*Populus x jackii*) seedlings, with these being natural intersectional hybrids between *P. balsamifera x P. deltoides*, the balsam poplar and prairie cottonwood, respectively. Calgary is upstream from the natural range limit of the prairie cottonwood, but there have been plantings within the City and substantial plantings of male clones of fast-growing clones that had probably been artificially produced. However, mitochondrial molecular markers indicate that only the *P. deltoides* parent can be the female and this would greatly limit the extent of the *P. x jackii*, since there would be few female *P. deltoides* trees and the more common planted hybrids would be males.

In addition to the five woody species, there were ten herbaceous plant species in the quadrats at Shrub Island (Table 3). These occurred sparsely with six species occurring in only one quadrat, there occurring in two quadrats, and quackgrass observed in three quadrats. Thus, colonization was primarily by native woody plants, with shrubs and balsam poplar trees.

Based on the pre-flood condition, we might expect that this low-lying island could be too low for the balsam poplars to survive and mature and the island could return to provide a fully covered shrubland. We might expect willows to be the predominant shrub, reflecting the persistence of some through the flood event and these would have a substantial advantage over the seedling-established plants. However, with the abundant chokecherry and other shrubs, Shrub Island might be expected to eventually support a community that included a few different shrub species. Based on the aerial photograph sequence, we might also expect some downstream extension of Shrub Island, possibly to connect with Wooded Island, thus forming a single, long, vegetated island.

Table 3. Plant species (in accordance with Tables 17 and 18) and respective occurrences and mean densities that were observed in each 1x1 m quadrat at the Shrub Island (SI) study site along the Bow River.

Quadrat	Number of Plants Observed														
	Woody Species					Herbaceous Species									
	Balsam poplar	Chokecherry	Jackii poplar	Manitoba maple	Sandbar willow	Alfalfa	Canada thistle	Chickweed	Dandelion	Horsetail	Prairie onion	Quackgrass	Sage	White clover	Willowherb
SI1	26	4	-	-	3	-	-	9	5	2	-	6	-	-	1
SI2	27	4	-	1	2	-	-	-	4	-	-	1	-	-	-
SI3	18	29	-	-	-	3	-	3	-	-	-	-	1	2	-
SI4	29	7	-	-	-	-	-	-	-	-	-	-	-	-	-
SI5	15	34	1	2	-	-	5	-	-	-	-	-	-	-	-
SI6	5	10	1	-	-	-	2	-	-	-	-	-	-	-	-
SI7	13	-	-	-	7	-	-	-	2	-	-	1	-	-	-
SI8	6	17	-	-	8	-	-	-	-	-	-	-	-	-	-
SI9	31	3	-	1	-	-	-	-	-	-	9	-	-	-	-
Occurrence (%)	100	89	22	33	44	11	22	22	33	11	11	33	11	11	11
Density (#/m^2)	21.3	13.5	1	1.3	5	3	3.5	6	3.7	2	9	2.7	1	2	1

Table 4. The numbers of average height (± SE) of the three tallest balsam poplar seedlings apparently established in 2013, 2014 and 2015 in each Shrub Island quadrat. The quadrat elevations above base river stage and inundation discharges are also shown.

Quadrat	Seedlings by Establishment Year				Total Seedlings	Height (cm)	Elevation (m)	Inundation *Q* (m^3/s)
	Older	2013	2014	2015				
SI1	-	-	17	9	26	-	0.56	254
SI2	-	-	9	18	27	-	0.65	206
SI3	-	-	3	15	18	-	0.46	200
SI4	-	-	20	9	29	13.7 ± 1.5	0.56	254
SI5	-	-	3	12	15	10.7 ± 1.2	0.56	411
SI6	-	-	-	5	5	8.7 ± 9.9	0.44	411
SI7	-	-	9	4	13	19.7 ± 2.1	0.40	254
SI8	6	-	-	-	6	107.0 ± 9.8	0.25	206
SI9	-	3	8	20	31	31.0 ± 14.7	0.57	206
Total	6	33	69	92	170			
Proportion	.035	.02	.405	.54	1			

Figure 13. Post-flood aerial photographs of Shrub Island in the Bow River, which were used to coordinate inundation discharges for that study site.

3. Wooded Island (WI)

In marked contrast to Shrub Island, Wooded Island was very unusual as an island in the Bow River that was apparently not inundated with the extreme 2013 flood (Figure 10). Although no aerial photograph exists from the flood crest (and rain and cloud would have impeded photography at that time), when we visited the island, we did not see evidence of flooding such as debris wrapped around trees, as was extensive in downstream woodlands that were inundated.

The island has a gradual rise at the upstream end, where flooding would have been more likely and there are then steep cut-banks along both sides and at the lower end of the island (Figure 12WI1 and WI2). These banks are actively slumping, with undercutting of the vegetation on island and hanging and fallen clumps of vegetation with the roots providing some adherence to the soil.

The vertical cut-banks display the history of deposition, with coarser material near the river edge and finer layer higher up. There are some gravel layers and layers of sands and there are also banks with silt and clays that are more cohesive. Above these sediment layers, the surface is covered with dense vegetation with a mixture of shrubs and herbaceous plants and some balsam poplar trees. Water birch or river birch (*Betula occidentalis*) was common, typically as a large shrub or small tree with multiple stems or trunks. Indicating a higher, drier environment, wolf willow was also common (or silverberry, *Elaeagnus commutata*, not a true (*Salix*) willow). Wolf willow is facultative riparian plant, occurring in upland as well as riparian zones. There were also various herbaceous plants, including the bushy Canada goldenrod (*Solidago canadensis*), which is classified as a facultative upland plant. The vegetation occurrence reflects the higher and drier status.

With slumping cut-banks on three of the four sides of Wooded Island, it would be expected that the island area would be shrinking. However, the size and position of the main island section appear very similar in the pre- versus post-flood aerial photographs suggesting very gradual erosion (Figure 10). There was apparent scour of shrubby vegetation on the ‘gooseneck’ from the upstream end of the island and this portion was lower in elevation and inundated with the 2013 flood.

4. Crowchild Island Bar (CIB)*

Across the main channel and downstream from Wooded Island, the Crowchild Island Bar was the largest and most complex feature that we studied (Figure 14 and 15). It occurs at the downstream end of the large wooded bar situated between the CP Railway line and the main Bow River channel. It represents a massive gravel bar with a back channel that extends from the downstream end and partially cuts off the bar from the river valley floodplain at low flows and with higher flows a channel severs the feature, creating an island. There is substantial sorting of surface sediments with some scrolls with scour or deposition and some curved bands with finer sediments.

Prior to the flood the complex consisted of a cluster of islands, with a substantial channel separating these features from the river bank, even at low flows (Figure 15 CIB-a). On the higher surfaces there were substantial zones of shrubs and trees, with a fairly large woodland patch situated slightly below the centre of the zone between the higher banks.

With the 2013 flood the whole complex was submerged (Figure 15, CIB-b, which was about four days after the crest) and there was extensive vegetation scour and deposition of gravels and cobbles. The depositions and scours are more vividly displayed with the nearly black and white aerial photograph of October 24, 2013 during the autumn following the flood (CIB-c). That post-flood photograph also displays the pond towards the centre of the island bar.

Vegetation recovery and expansion is displayed in the aerial photograph from August 22, 2015, three days after our field surveys of this site (CIB-d). As shown, the former island cluster has had substantial deposition and with the raised elevation, it has become more of a bar feature, with attachment to the river right bank.

Figure 16 provides the same, August 22, 2015 aerial photograph, with the shrub and woodland patch outlines from the pre-flood photograph of September 22, 2012. As shown, the major woodland patch was largely eliminated, with only a few scattered shrubs and trees remaining at the upstream end. The adjacent smaller patch has had the vegetation removed and this is probably due to deposition, with a band of willows surviving at a steeper slope falling away at the downstream end. This interesting feature resembled a sand dune but built with coarse gravel transported by water, rather than involving wind-borne sand.

The vegetation patches in the downstream positions were largely intact (Figure 16). There are also some sparser patches that persisted. The major change involved a massive deposition of coarse sediments in the upstream zones, with toppling and scour of the prior, large woodland patch, but more limited changes in the downstream zones.

The positions of transects and quadrats on the Crowchild Island Bar are plotted in Figure 17. We deliberately crossed the pond (Figure 17, near CIB5; Figure 18, CIB1 'a'). We found that the water surface elevation was similar to that adjacent river surface to the northeast (by Figure 17 CIB6). This indicates high hydraulic conductivity across this portion of the island, as we had expected. From this finding, we would anticipate that the groundwater table would represent a near-horizontal extension from the river and there would be rapid rise and fall in groundwater, in association with the changes in river stage. Conversely, we found a downward step to the stage of the backwater southwest of the pond. This would suggest more gradual subsurface flow, and possibly reflect a band of finer material that would impede groundwater flow. The aerial mosaic photograph for Figure 17 also displays extensive algae in the pond on the island, and also in the backwater channel along river-right, possibly suggesting a nutrient plume.

Along the transect down-island through the pond, a willow patch that survived the flood is displayed in Figure 18, CIB1 'b'. This cluster of photographs also displays other willow patches and these included other willow species in addition to sandbar willows, which were abundant and probably newly colonized (Figure 19, CIB7). We have taken photographs of the flowers on willows on the Point McKay bar and will seek further identifications from these.

Willows represented the most abundant plants on the Crowchild Island Bar with a number of the patches displayed in Figures 18 and 19. Of particular interest, Figure 18, CIB3 'c' displays the remnant willows at the upstream end of the large shrub patch that occurred prior to the flood (Figure 16). This confirms the exceptional flood adaptation of willow as we observed at the Bowmont Park site. In contrast to that flood tolerance, there were remnants of river birch shrubs and other shrubs with toppled and sheared stems (Figure 18, CIB3 'd'), also confirming the observation at Bowmont Park and other sites.

We observed abundant new balsam poplar seedlings and saplings on the Crowchild Island Bar as displayed in photographs (Figure 18, CIB3 'e', including those of sufficient size to indicate establishment in the flood year, 2013 (Figure 18, CIB5). Willows represented the primary surviving plants and balsam poplar represented the primary colonizers, with willow seedlings also occurring (Tables 5 and 6). We thus anticipate extensive woodland development on the Crowchild Island Bar, in addition to the colonization and expansion of shrubland zones dominated by willows. As this shrubland and woodland patches develop we would also expect some sediment trapping and colonization and succession to produce a more biodiverse riparian zone. While we didn't find seedlings of other woody plants such as birch or Manitoba maple, there are abundant mature shrubs and trees on the adjacent hillslope (Figure 18, CIB6). While there may be concerns relative to directing the river flow to the north bank, with the anticipated riparian vegetation development, we would expect that the Crowchild Island Bar could develop into a very rich riparian habitat for birds and other wildlife.

Figure 14. An upstream view of the Crowchild Island Bar study site in the Bow River, July 12, 2015.

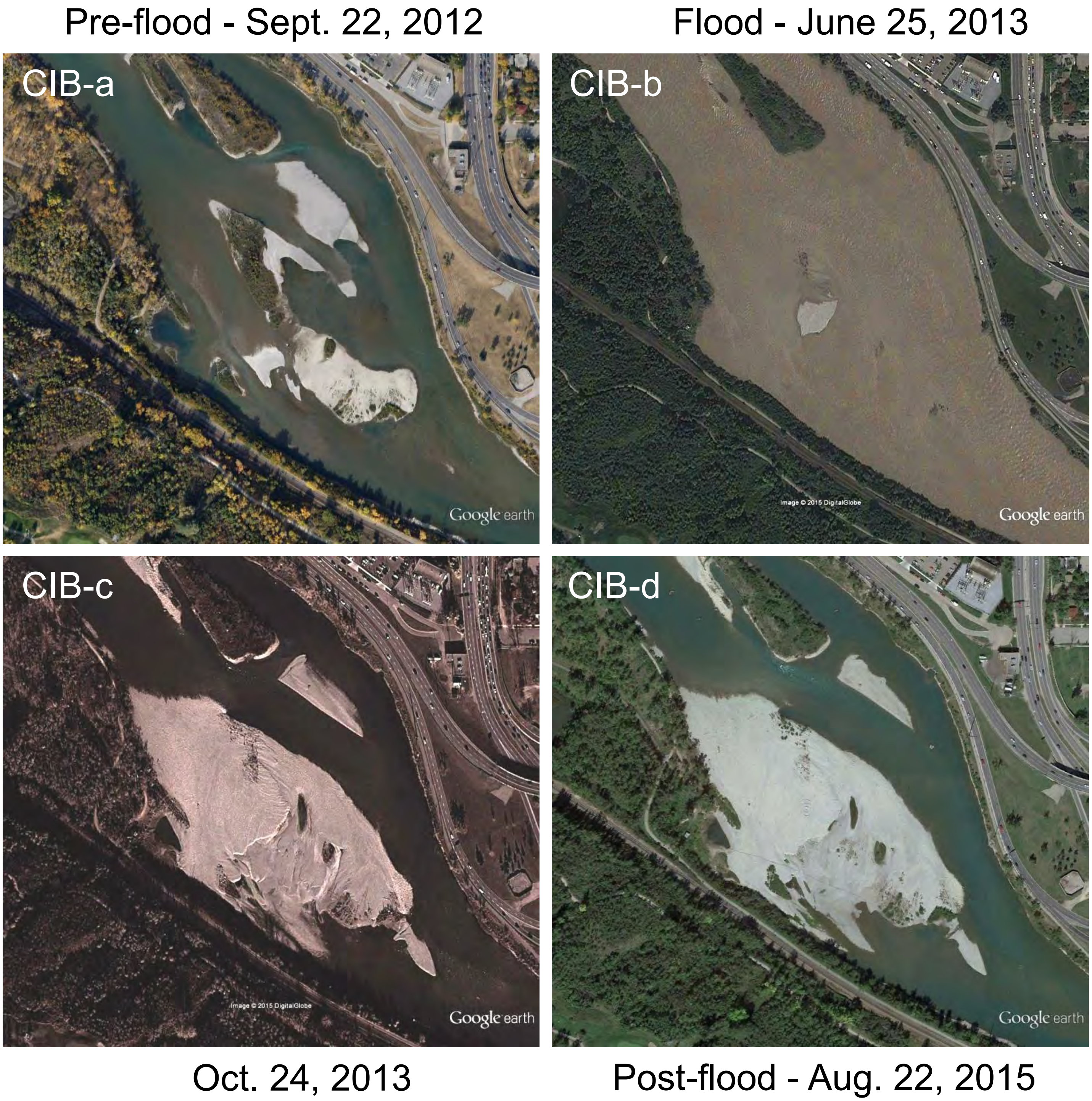


Figure 15. Aerial photographs of the Crowchild Island Bar (CIB) study site along the Bow River. These display conditions prior to the 2013 flood (CBI-a) and during the flood. The 2013 photograph displays the depositional features and the final photograph displays conditions at about the time of the field sampling.

Post-flood Aug 22., 2015

Figure 16. An aerial photograph of the Crowchild Island Bar with outlines showing woodland patches from Sept. 22, 2012 (Figure 15).

Figure 17. A post-flood aerial photograph of Crowchild Island Bar along the Bow River, with the study transects and quadrat locations plotted.

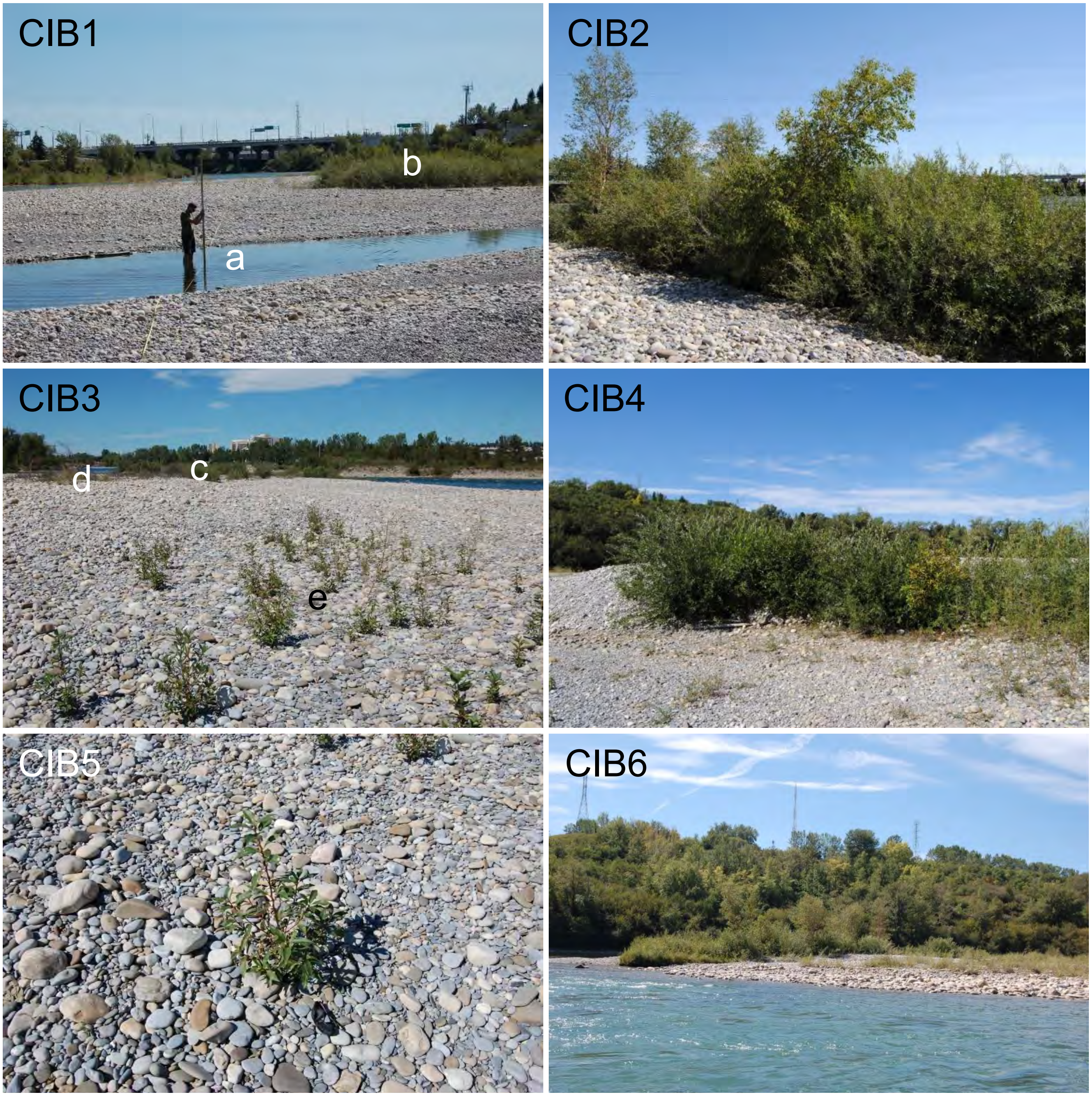


Figure 18. Ground level photographs at the Crowchild Island Bar.

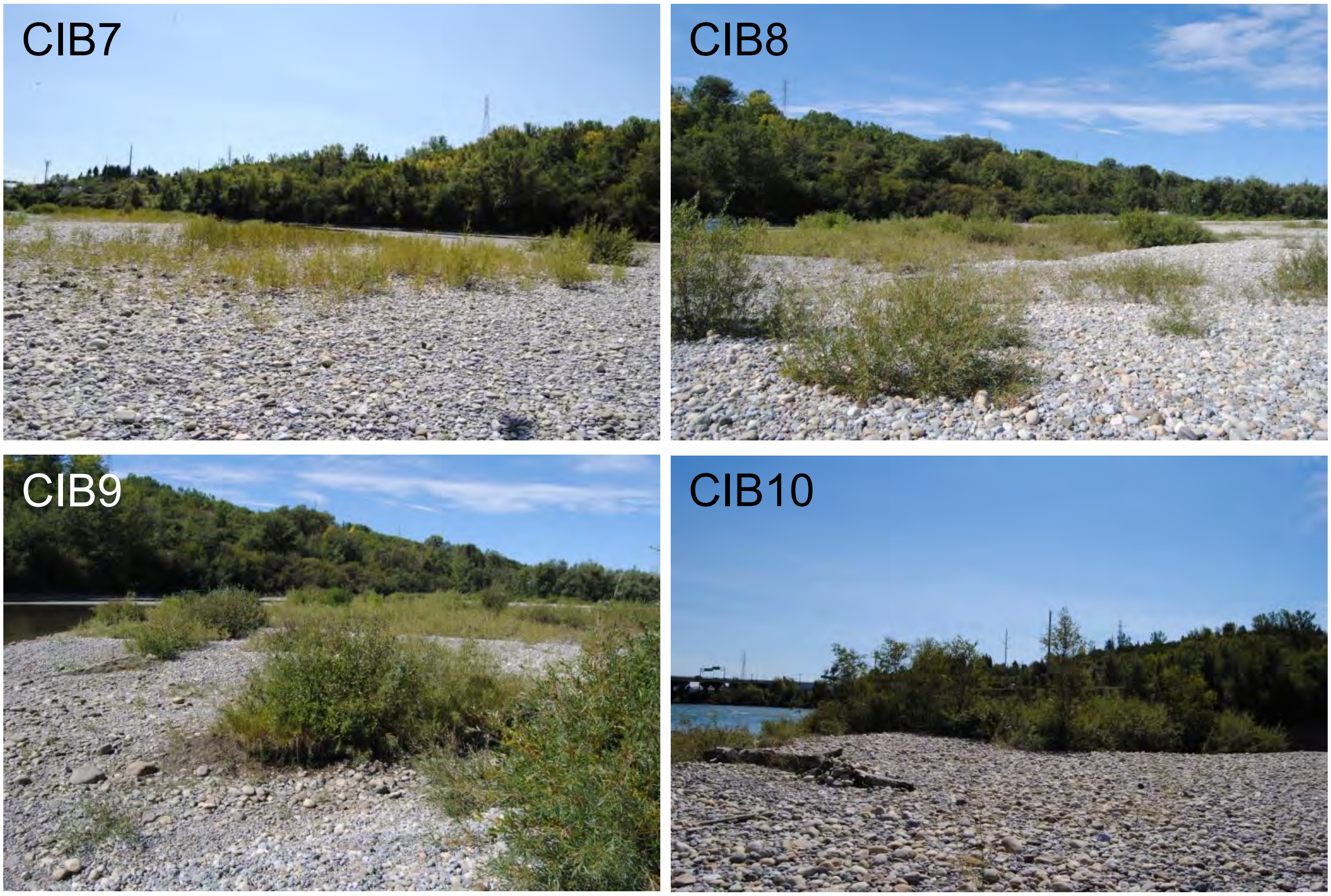


Figure 19. Ground level photographs at the Crowchild Island Bar continued.

Table 5. The number and density of plant species observed in 1x1 m quadrats surveyed on the Crowchild Island Bar (CIB) along the Bow River.

Quadrat	Plants Observed					
	Woody Species		Herbaceous Species			
	Balsam poplar	Sandbar willow	Aster	Dandelion	Quackgrass	White clover
CIB1	10	-	-	-	-	-
CIB2	-	8	-	-	-	-
CIB3	5	-	-	-	2	1
CIB4	-	-	-	-	-	1
CIB5	2	-	-	1	1	-
CIB6	-	8	-	-	-	-
CIB7	7	-	-	-	-	-
CIB8	-	-	-	1	2	-
CIB9	1	-	2	1	-	-
CIB10	1	-	-	-	-	-
Occurrence (%)	60	20	10	30	30	20
Density (#/m^2)	4.3	8	2	1	1.7	1

Table 6. The numbers and mean height $\pm$ SE of the three tallest balsam poplar seedlings apparently established in 2013, 2014 and 2015 in each quadrat at the Crowchild Island Bar (CIB) site. Respective quadrat elevations above base river stage and inundation river discharges also shown.

Quadrat	Seedlings by Establishment Year			Total Seedlings	Height (cm)	Elevation (m)	Inundation *Q* (m^3/s)
	2013	2014	2015				
CIB1	-	-	-	0	-	1.09	200
CIB2	1	-	-	1	-	1. 45	411
CIB3	1	-	-	1	-	1.84	411-693
CIB4	-	-	-	0	-	0.99	254
CIB5	-	2	-	2	13.5 ± 4.9	0. 67	254
CIB6	-	-	-	0	-	0.20	200
CIB7	6	1	-	7	47.0 ± 8.9	1.34	411-693
CIB8	1	4	5	10	21.3 ± 7.6	0.64	200
CIB9	-	-	-	0	-	1.52	200
CIB10	-	4	1	5	-	0.54	254
Total	9	11	6	26			
Proportion	.35	.42	.23	1			

5. Bar Above 10th St. (BAT)

We considered the island bar along the river-left side upstream of the 10th St. Bridge as a useful reference site relative to flows and elevations related to that bridge (Figure 20). Prior to the 2013 flood, that feature involved an elongated island zone with a substantial back channel between it and the left bank (Figure 21, TSI-a). It was densely covered with shrubs but apparently not with trees, as evidenced by the more homogeneous cover than the woodland patch at the 10th St. Bridge, which supports trees as well as shrubs (Figure 12, TSI-a).

The full bar was inundated with the 2013 flood and there was substantial scour, as indicated in the post-flood aerial photograph (Figure 12, TSI-c). The river had apparently thinned out the shrub zone and also created a cleared channel from the centre of the river, left to the enlarged backwater channel. We visited this bar in August 19, 2015 and observed large and dense shrubs, and particularly willows, including sandbar willows. With the thinning, we might expect that some other shrubs such as river birch might have been particularly removed, as we observed at Bowmont Park. We took some elevational measurements and did not observe substantial seedling colonization of the newly cleared diagonal channel. We thus conclude that this provides a flow path with higher river levels and this would remove new seedlings. With the lack of new seedlings we did not undertake any vegetation quadrats but it would be worthwhile to revisit this location in future summers. While the lower portion is separated by the back channel, the upper portion is connected to the left bank and the site could be readily revisited without the need for boat access.

Figure 20. An upstream view of the Bar Above 10th St. site in the Bow River, July 12, 2015.

Pre-flood
Sept. 22, 2012
60 m^3/s
eye alt 4672 ft

Flood
June 25, 2013

Post-flood
Field visit
Aug. 21, 2015

Figure 21. Aerial photographs of the 10th Street Island (TSI) study site in the Bow River. These display conditions prior to the 2013 flood (TSI-a) and during the flood (TSI-b). The 2013 photograph displays the depositional features and the final photograph displays conditions at about the time of the field sampling

6. 10th St Island (TSI)*

The 10th St. Island was a primary site of interest relative to the possible development of a riparian woodland that could impede river conveyance. It was also an especially interesting site relative to the channel and riparian processes, and impacts from the major 2013 flood.

Prior to the flood, an island complex existed below the 10th St. Bridge and this supported a woodland grove with shrubs and balsam poplar (Figure 21, TSI-a). The woodland occupied much of the prior island surface, with some barren, lower elevational zones extending upstream and downstream. The whole island was probably inundated during the 2013 flood, with the shrub and tree shoots emerging from the flood waters (TSI-b). There was apparently extensive sediment deposition and consequently the island was greatly expanded by the 2013 flood (Figure 21, TSI-c; Figure 22). The island expanded upstream and downstream and was enlarged to river right and thus attached to a prior smaller island to provide a large island that extended from the 10th St. Bridge downstream to the LRT Bridge and even further downstream at low river flows. In the sequence of aerial photographs it is noteworthy that the pre-flood photo represents the island exposure at 60 m^3/s, while the post-flood photo reveals the much more extensive island exposure even with the slightly higher river discharge (about 80 m^3/s). Thus, the 10th St. Island was vastly expanded by the 2013 flood.

On the newly expanded island zone upstream from the 10th St. Bridge, the surface was predominantly coarse gravel to small cobble (Figure 24), and this was relatively flat and at fairly low-elevation relative to the adjacent river surface. In mid-July, this upstream zone was sparsely colonized by sweetclover and those plants had senesced by the field visit in late August (Figure 24, TSI4). There were some small seedlings of balsam poplars and other woody plants on the upstream zone, with the small size indicating establishment in 2015 and there might be limited prospect for survival due to the low elevation.

The island surface was progressively higher near the Bridge and highest near the bridge pier at the river left edge of the island. This was the zone where the woodland grove previously existed. The grove had been scoured by the flood flow and some of the shrubs and trunks were toppled, but were regrowing upright and thus rebounding from the scour. A single large balsam poplar occurred just upstream from the bridge and its canopy extended above the bridge in July 2015. By mid-August it had been decapitated, possibly due to strong wind (Figure 25, TSI6).

The woodland grove upstream of the 10th St. Bridge that existed before the 2013 flood largely survived the flood (Figure 22). In contrast, the smaller shrub patch downstream of the bridge pier was completely lost (Figure 22). This was probably scoured away since there was no evidence of remaining material that had been toppled and covered. Supporting this interpretation, we did not see remnant material, as we observed at the Crowchild Island Bar, or new clonal shoots that would be emerging from covered shrubs.

The zone was higher than the rest of the island downstream of the 10th St. Bridge and it is likely that this reflects some sediment settling in the protected location downstream of the bridge pier. We observed many balsam poplar saplings on this raised crest that was parallel to the river channel (Figure 24, TSI3; Figure 26, TSI9 and TSI10; Table 8). Some of these new poplars had probably been established in the flood year, 2013, with more established in the following year, 2014 (Table 8). As some poplars have thus survived through three growth seasons are approaching a half meter in height, we anticipate that these will persist to provide a woodland downstream from the 10th St. Bridge, with the area that was the woodland grove prior to the flood, being the first zone to substantially mature.

We also observed other balsam poplar seedlings and saplings on the lower portion of the 10th St. Island (Table 8) and we thus anticipate that the downstream woodland will be much larger than the small grove that existed prior to the 2013 flood. With more extensive woodland on the island, we might anticipate that this could impede future flood flows through the channels below the Bridge. This would then lead to elevated river levels and increase future flooding at this location. In addition to the flow impediment from the shrubs and trees, we might also expect some further trapping of alluvial sediments and this would also reduce the flow area, especially below the middle span of the bridge, where the island may now be high enough to permit woodland development across that full bridge gap. With further woodland colonization and succession, we anticipate that the condition at the 10th St. Bridge might resemble that at the Mission St. Bridge on the Elbow River (Elbow River Park, Site #12, following).

The process of woodland colonization, growth and succession takes time and we might anticipate that the accuracy of our predictions should be evident within a decade. If we are correct and a considerable woodland develops on the 10th St. Island, and if this would impeded future flood flows, it could be appropriate to clear the woodland vegetation and excavate part of the island, to provide a lower surface that would be less prone to recolonization. We thus recommend that particular attention be paid to the anticipated woodland development on the 10th St. Island.

Figure 22. An aerial photograph of the 10th Street Island (TSI) with an outline showing the woodland patches from Sept. 22, 2012 (Figure 21).

Figure 23. A post-flood aerial photograph of 10th St. Island in the Bow River showing the study transects and quadrat locations.

Facing upstream, the prospect of flow impedance is shown below the 10th St. Bridge. A woodland patch existed upstream prior to the 2013 flood and survived that scour. Sediment was deposited downstream from the patch and on the island, expanding it, as evidenced by sequential aerial photographs and very probably elevating it through deposition of cobbles and other sediments (Aug. 8, 2015).

Probably due to the bridge support, combined with flow blockage from the prior woodland patch, an elevated ridge occurs downstream and that now supports a new patch of balsam poplar saplings. These are high enough relative to the river that they are likely to survive and result in an elongated woodland band that extends downstream from the bridge support. This woodland band would trap sediments from future high flows, and thus further elevate the ridge, enabling expansion of the woodland patch (Aug. 19, 2015).

Figure 24. Ground level photographs at the 10th St. Island in the Bow River.

The predominant vegetation on island the 10th St. Bridge was white clover and this had died back by August. Sparse woody saplings occurred but these zones are lower and survival may be less likely.

(top - towards the river right bank, and centre (left) facing upstream.)

The woodland patch on the island immediately upstream from the 10th St. Bridge includes willows, river birch and balsam poplar and was not removed by the 2013 flood. Shrubs were toppled but have regrown more upright. The single large balsam poplar was decapitated between late July and mid-August, probably due to strong wind or possibly a lightning strike.

Figure 25. Ground level photographs at the 10th St. Island continued.

Figure 26. Further ground level photographs of the 10th St. Island study site.

Table 7. Plant species and respective occurrences and densities that were observed in each 1x1 m quadrat at the 10th Street Island (TSI) study site along the Bow River, Calgary, AB.

Quadrat	Number of Plants Observed									
	Woody Species		Herbaceous Species							
	Balsam poplar	Chokecherry	Aster	Canada thistle	Dandelion	Horsetail	Pineappleweed	Plantain	Quackgrass	White clover
TSI1	-	-	-	-	1	1	-	-	-	-
TSI2	4	1	-	-	1	-	-	-	1	-
TSI3	1	1	1	-	2	-	-	1	1	-
TSI4	7	-	-	-	1	-	-	-	-	-
TSI5	6	-	-	-	-	-	-	-	-	1
TSI6	8	1	-	5	4	-	2	-	8	-
Occurrence (%)	83	50	17	17	83	17	17	17	50	17
Density (#/m^2)	5.2	1	1	5	1.8	1	2	1	3.3	1

Table 8. The numbers and mean height of the three tallest balsam poplar seedlings estimated to have been established in 2013, 2014, 2015 in each quadrat and quadrat at the 10th Street Island (TSI) study site. Respective quadrat elevations above base river stage and inundation river discharges are also shown.

Quadrat	Seedlings by Establishment Year			Total Seedlings	Height (cm)	Elevation (m)	Inundation Q (m^3/s)
	2013	2014	2015				
TSI1	-	-	-	0	-	0.78	245
TSI2	-	3	1	4	-	0.84	206
TSI3	-	1	-	1	-	0.82	206
TSI4	3	4	-	7	32.0 ± 7.2	0.70	245
TSI5	1	5	-	6	-	0.99	411
TSI6	-	-	8	8	-	0.48	301
Total	4	13	9	26			
Proportion	0.15	0.50	0.35	1			

7. Centre St Bar (CSB)*

The Centre St. Bar exists along the river left (north) bank, downstream from the Centre St. Bridge. It had been identified as a location of concern relative to the prospective woodland colonization below the left span of the Bridge and associated impedance of flow conveyance.

Prior to the 2013 flood there was a small bar under the left edge of the Bridge, and a shallow submerged bar, with islands emerging at very low flows (Figure 27). Following the 2013 flood, this shallow zone has emerged and has become an extensive shallow bar that represents about one-third of the channel width and extends through the left span, one of three below the bridge (Figures 27 and 28). If this bar were wooded it would be likely to restrict the flow through the left span.

The extensive bar is relatively flat and as the river slopes down, the lower zones of the bar become relatively higher, with respect to the adjacent water surface. With the field visits the upstream end of the bar below the bridge was just about at the water level and would thus be inundated through much of the summer. Conversely, the lower zones of the elongated bar would be exposed through typical summer flows.

The vegetation on the CSB was substantial and diverse (Figure 29). We observed 15 plant species within only five quadrats (Table 9); we regarded these outcomes as representative for the bar. Balsam poplar seedlings were common, along with other woody plants, river birch, alder, and chokecherry (Table 9). While only one Manitoba maple seedling occurred in the quadrats, we observed many more saplings closer to the bank where some larger Manitoba maples were well established, and probably provided the seed source. No willow seedlings occurred in the quadrats but these were observed on the bar, although sparsely. In addition to the woody plants there were abundant herbaceous plants, with various weeds occurring (Table 9) but these would probably not hinder the woodland colonization by the native balsam poplars and shrubs. Following from the abundance and diversity, it would be likely that the lower portions of this newly emerged bar could be colonized by a complex woodland community with a blending of native and introduced plants.

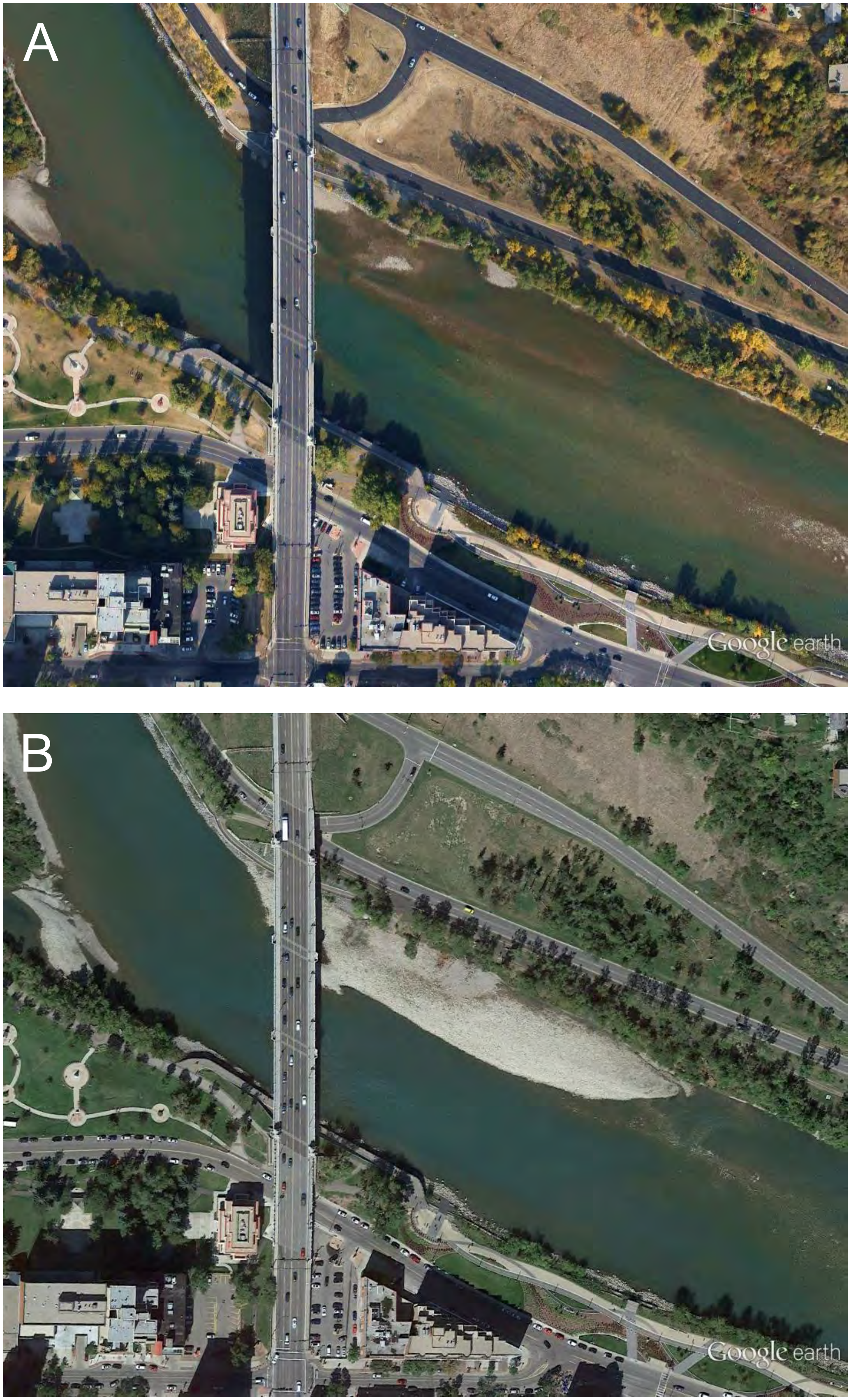
The condition of the bar, with abundant balsam poplar seedlings (Table 10), resembled bars along the Bow River downstream of the Highwood River, following the 1995 and 2005 floods of that river and the Bow River downstream. We might thus expect the CSB to follow a similar sequence, with growth of the poplars and other shrubs to form a dense woodland within a decade. Since this woodland would be downstream from the bridge, it would not provide the flow impediment that might arise at the 10th St. Bridge, or already occurs at the Mission Bridge on the Elbow River. Conversely, this Bridge is right in downtown Calgary and any flow impediment may be disfavored. Given the substantial initial colonization, we expect the woodland to develop rapidly on the Centre St. Bar and would anticipate that within a decade, the prospective hazard should be readily assessed.

Table 9. Plant species and respective occurrences and densities that were observed in each 1x1 m quadrat at the Centre Street Bar (CSB) study site along the Bow River.

Quadrat	Number of Plants Observed												
	Woody Species				Herbaceous Species								
	Alder / Birch	Balsam poplar	Chokecherry	Manitoba maple	Alfalfa	Aster	Canada thistle	Dandelion	Foxtail barley	Pineappleweed	Quackgrass	White clover	Willowherb
CSB1	4	5	-	-	-	18	-	8	1	-	8	-	2
CSB2	-	20	-	-	3	-	-	4	-	-	10	-	-
CSB3	9	-	3	1	-	4	-	3	-	-	-	1	-
CSB4	4	-	-	-	-	-	-	-	3	-	3	8	7
CSB5	-	-	3	-	-	-	6	4	-	6	-	-	-
CSB6	-	1	-	-	-	-	-	-	-	-	-	-	-
Occurrence (%)	60	50	40	20	20	40	20	80	40	20	60	40	40
Density (#/m^2)	5.7	8.7	3	1	3	11	6	4.8	2	6	7	4.5	4.5

Table 10. Balsam poplar seedlings apparently established in 2013, 2014 and 2015 in each quadrat at the Centre Street Bar (CSB) site along the Bow River. Quadrat elevation above base stage and approximate inundation river discharge.

Quadrat	Seedlings by Establishment Year			Total Seedlings	Height (cm)	Elevation (m)	Inundation Q (m^3/s)
	2013	2014	2015				
CSB1	-	-	5	5	-	0.38	206
CSB2	-	-	20	20	-	1.08	301
CSB3	-	-	-	0	-	1.12	301
CSB4	-	-	-	0	-	0.72	200
CSB5	-	-	-	0	-	0.74	200
CSB6	-	1	-	1	-	1.32	411 - 693
Total	0	1	25	26			
Proportion	0	0.04	0.96	1			



Pre-flood
Sept. 22, 2012

Post-flood
Aug. 22, 2015
eye alt
1.43 km

Figure 27. Aerial photographs of the Centre Street Bar (CSB) study site along the Bow River. These display conditions prior to the 2013 flood (A). The final photograph (B) displays conditions at about the time of the field sampling.

Figure 28. A post-flood aerial photograph of Centre Street Bar along the Bow River showing the study transects and quadrat locations.

Figure 29. Ground level photographs of the Centre St. Bar study site along the Bow River, July 12, 2015.

8. Glenmore Trail Bar (GTB)*

The Glenmore Trail Bar was selected as a gradually sloping meander point bar, situated at the river put-in to access the Carburn Park Island (Figures 30 and 31). The bar is primarily upstream of the Glenmore Trail Bridge (Figure 32, GTB6) and continues to serve as a primary access location for launching boats into the Bow River. A prior concrete boat-ramp into a back channel is no longer useful due to extensive sediment deposition. Boats are now launched directly from the gravel bar and there is also a barren laneway as vehicles have driven to the upstream end (GTB2). The surface substrate includes two relatively distinctive particle size groups (GTB3, 4, 5, 7). There are large cobbles and much smaller gravels sifted in between. The pattern was widespread along the meander lobe (GTB1, 6).

This meander lobe clearly displays the elevational banding of vegetation types. The largest band of new vegetation is predominately balsam poplar seedlings, which extend from the step up the previously established vegetation for about 50 meters towards the river (Figure 32, GTB1, 3). These include abundant seedlings from 2014 and even more numerous but much smaller seedlings from 2015 (Table 12). At the slightly lower zone closer to the river, there is a transition with increasing proportion of sandbar willow seedlings (GT4). Extending from the willow band down towards the river, there is a fairly abrupt transition to a weedy zone, with abundant reed canarygrass (GTB5). These provide arcuate bands, which follow the curve of the meander lobe at particular elevations above the river water surface. This progressive banding is instructive relative to the elevational preferences of the three predominant riparian plants, balsam poplar, sandbar willow, and reed canarygrass. However, the banding can also reflect the seeding phenology, with poplar seeds being released for a short interval in early summer, and willows following, while some weeds display a broader seed release interval. The vegetation in the three bands was reflected in the compositions of the three quadrats (Figure 31; Figure 32 GTB1, 2, 3) that were positioned to represent the three seedling community types (Table 11).

At the lower end of the meander lobe there is a steeper bank along the backwater channel that provided the prior boat launch route. On this bank there is a dense band of reed canarygrass, with larger size than the seedlings observed, indicating that these plants persist from prior to the 2013 flood (Figure 32 GTB8). This dense banding of established reed canarygrass was not uncommon along the downstream segment of the Bow River through Calgary.

Figure 30. A post-flood aerial photograph of Glenmore Trail Bar along the Bow River showing the study transects and quadrat locations.

Figure 31. Post-flood aerial photographs of Glenmore Trail Bar in the Bow displaying the inundations at different river discharges that were used to project vegetation colonization patterns.

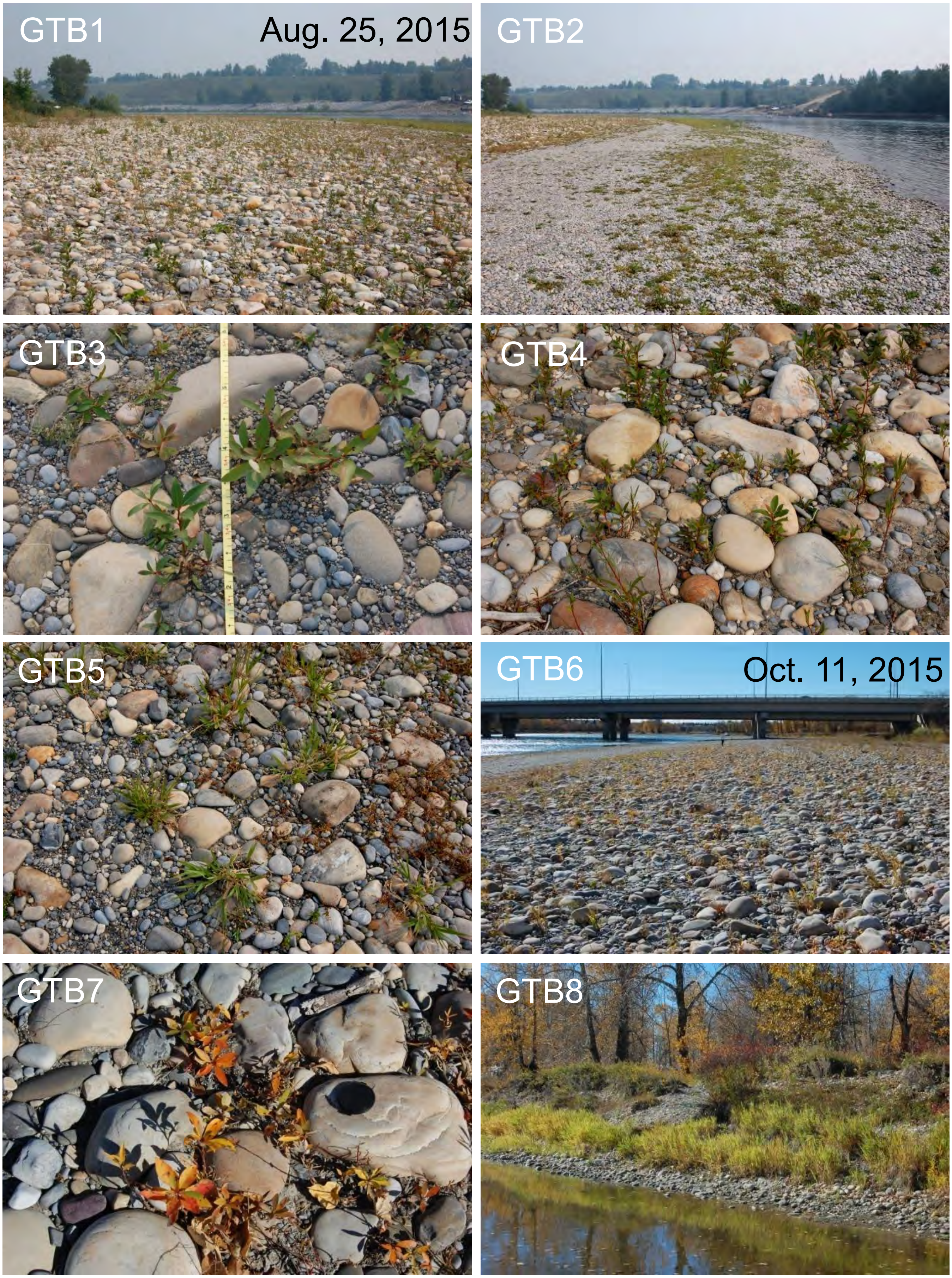


Figure 32. Ground level photographs at the Glenmore Trail Bar.

Table 11. Plant species and respective occurrences and densities that were observed in each 1x1 m quadrat at the Glenmore Trail Bar (GTB) study site along the Bow River, Calgary, AB.

Quadrat	Number of Plants Observed							
	Woody Species		Herbaceous Species					
	Balsam poplar	Sandbar willow	Canada thistle	Dandelion	Narrowleaf dock	Quackgrass	Reed canarygrass	White clover
GTB1	36	-	2	2	-	-	-	3
GTB2	10	2	-	-	-	1	-	-
GTB3	3	-	-	-	1	1	10	-
Occurrence (%)	100	33.3	33.3	33.3	33.3	66.6	33.3	33.3
Density (#/m^2)	16.3	2	2	2	1	1	10	3

Table 12. The numbers of balsam poplar seedlings estimated to have been established in 2013, 2014 and 2015 in each quadrat at the Glenmore Trail Bar (GTB) site on the Bow River, Calgary, AB. Respective quadrat elevation above base river flow and inundation river discharge are also shown.

Quadrat	Seedlings by Establishment Year			Total Seedlings	Quadrat Elevation (m above base stage)	Inundation Q (m^3/s)
	2013	2014	2015			
GTB1	-	2	34	36	1.0	411-693
GTB2	-	8	2	10	0.7	301
GTB3	-	2	1	3	0.5	301
Total	0	12	37	49		
Proportion	0	.24	.76	1		

9. Carburn Park Island (CPI)*

The Carburn Park Island represents the outcome from a very artificial situation, with a narrow ring of mature balsam poplar woodland around a pre-flood pond. With the 2013 flood, the upstream bank was breached and water flowed into and through the pond, breaking out through the downstream bank. There is still a remaining narrow, elevated band that follows the river route, with the prior channel down the right side and the new channel down the left, through the zone of the prior pond (Figure 33).

The newly established zones are quite level with the surface substrate including the largest particles that we encountered, with abundant large cobbles and boulders (Figure 34). There were some gravels and also finer, interstitial sands and silts settled in between the larger sediments. This unusual substrate could reflect the artificial nature of the site.

The newly established riparian vegetation was rather different than at any other study site. It included a mixture of weeds (Figure 34, Table 13) with abundant reed canarygrass, along with stinging nettle, toadflax, dandelion and Canada thistle in the vegetation quadrats, and other weeds were also observed, but less abundant. There were some balsam poplar seedlings (Figure 34 CPI6, Table 14) as well as other woody seedlings, with some Manitoba maple seedlings appearing healthy (CPI7). However, the weeds were much more abundant and we anticipate that over the next few years, the newly formed, low-lying zone may become predominantly reed canarygrass. This island complex provided the most weed-infested site that we assessed and we did not observe another similar situation as we viewed other bars and islands along the Bow River through Calgary. The weed infestation at CPI was somewhat similar to that at the culvert outflow zone at the Carseland Weir Bypass, which also followed from the flood breach of an artificial structure.

Figure 33. A post-flood aerial photograph of Carburn Park Island (CPI) in the Bow River showing the study transects and quadrat locations.

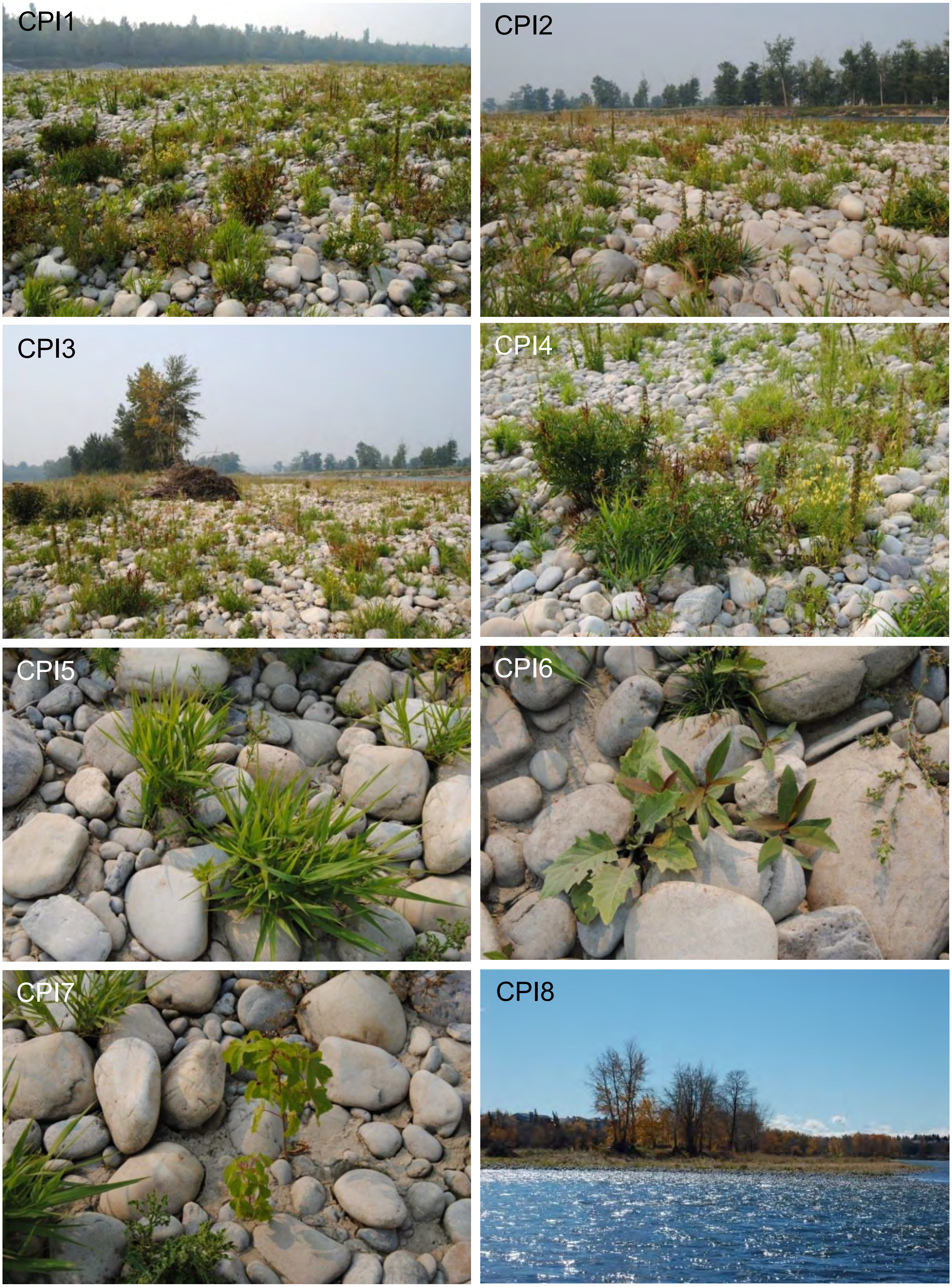


Figure 34. Ground level photographs at the Carburn Park Island.

Table 13. Plant species and respective occurrences and densities that were observed in each 1x1 m quadrat at the Carburn Park Island (CPI) study site along the Bow River, Calgary, AB.

Quadrat	Number of Plants Observed												
	Woody Species				Herbaceous Species								
	Alder / Birch	Balsam poplar	Jackii poplar	Manitoba maple	Canada thistle	Dandelion	Narrowleaf dock	Pineappleweed	Plantain	Reed canarygrass	Stinging nettle	Tansy	Yellow toadflax
CPI1	1	-	-	-	5	-	-	2	-	5	-	-	-
CPI2	-	7	1		-	2	1	-	1	3	-	2	2
CPI3	-	-	-	1	3	6	-	-	-	3	13	-	-
CPI4	-	4	-	3	2	-	-	-	1	2	4	-	-
Occurrence (%)	25	50	25	25	75	50	25	25	50	100	50	25	25
Density (#/m^2)	1	5.5	1	2	3.3	4	1	2	1	3.3	8.5	2	2

Table 14. The numbers of balsam poplar seedlings estimated to have been established in 2013, 2014, 2015 and average seedling height of the three tallest seedlings in each quadrat at the Carburn Park Island (CPI) site along the Bow River, Calgary, AB. Respective quadrat elevation above base river flow and inundation river discharge are also shown.

Quadrat	Seedlings by Establishment Year			Total Seedlings	Height (cm)	Elevation (m)	Inundation *Q* (m^3/s)
	2013	2014	2015				
CPI1	-	-	-	0	-	0.45	301
CPI2	-	-	7	7	-	0.27	301
CPI3	-	-	-	0	-	0.53	301
CPI4	-	4	-	4	12.3	0.27	301
Total	0	4	7	11			
Proportion	0	.36	.64	1			

10. Hull's Wood Bar (HWB)*

We have been regularly revisiting the meander lobe at Hull's Wood (Figures 35, 36) since the autumn of 2013, in the summer of the flood year (Table 2). We observed many 2013 balsam poplar seedlings in the spring of 2014, as well as clonal suckers (Figure 37, HWB5) that were apparently stimulated with root scarification, the abrasion of the shallow, horizontal roots. This was not a priority site relative to risk to infrastructure or elevated flood stage and was more important for our analyses of the pulse of woodland recruitment following the 2013, which was the focus of the Watershed Resiliency and Restoration Program project.

We observed abundant new seedling on the meander lobe point bar (Figure 35), which was expanded by the 2013 flood. Balsam poplar seedlings were common, and included a few from 2013, more from 2014 and abundant but very small seedlings from 2015 (Figure 37, Table 16). Two problem plants were also common, with new seedlings of reed canarygrass and the noxious weed, leafy spurge (Figure 37, Table 15). The seedlings were sparsely distributed and thus the weeds might not impede the new poplar seedlings. As the poplar seedlings grow in height, they will be above the weeds by about the fifth year and might subsequently not be hindered by the invasive plants. Instead, the growing balsam poplars would tower over the weeds and provide shading, thus stressing and possibly excluding the shade-intolerant weeds.

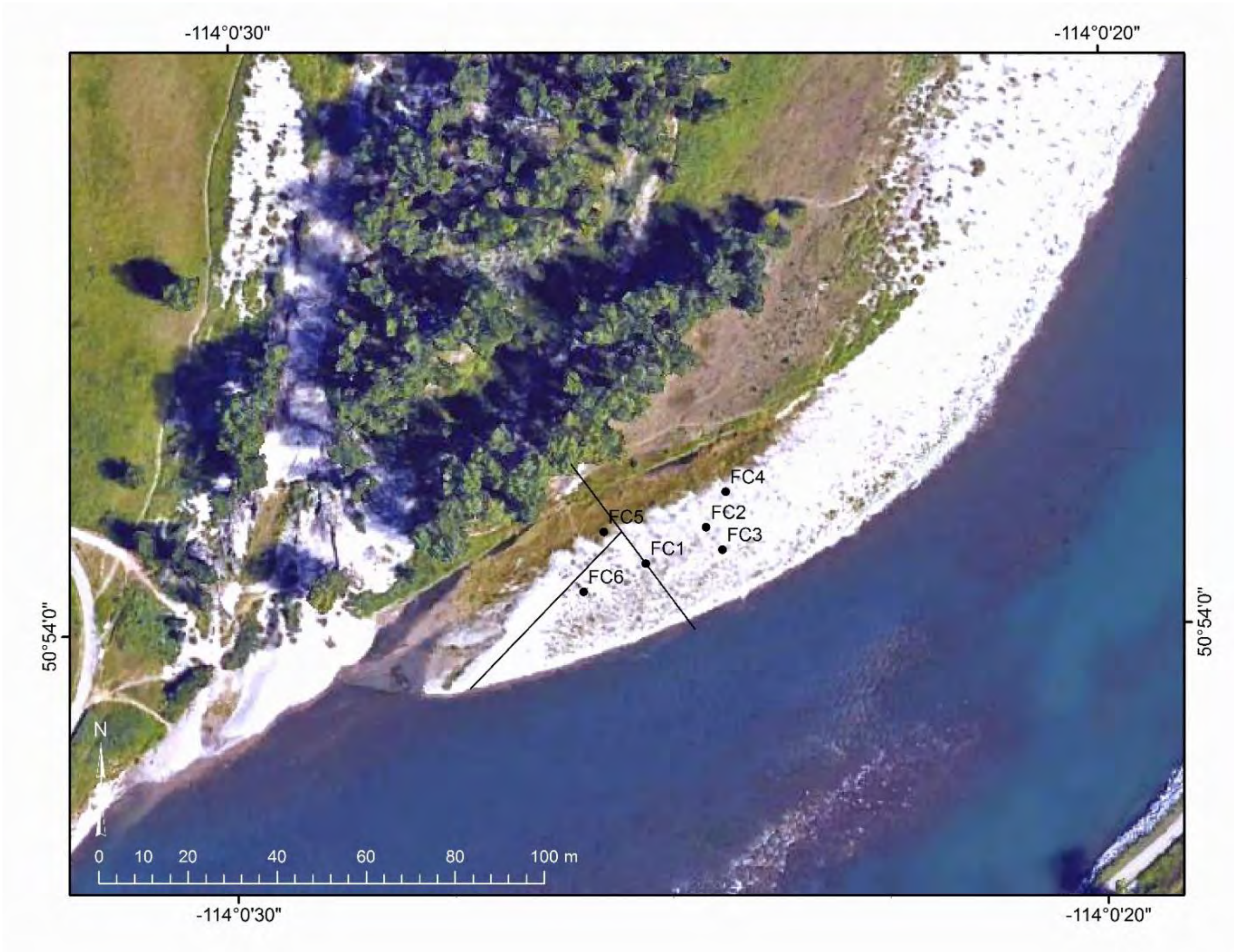


Figure 35. A post-flood aerial photograph of Hull's Wood Bar (HWB) along the Bow River showing the study transects and quadrat locations.

Figure 36. Post-flood aerial photographs of Hull’s Wood Bar along the Bow River displaying the inundations at different river discharges that were used to assess vegetation colonization patterns.

Figure 37. Ground level photographs taken on July 12, 2015 at the Hull's Wood Bar (HWB).

Table 15. Plant species and respective occurrences and mean densities that were observed in each 1x1 m quadrat at the Hull's Wood Bar (HWB) study site along the Bow River.

Quadrat	Number of Plants Observed							
	Woody Species	Herbaceous Species						
	Balsam poplar	Alfalfa	Canada thistle	Dandelion	Leafy spurge	Narrowleaf dock	Reed canarygrass	Sweetclover
HWB1	9	-	2	2	4	-	7	3
HWB2	1	-	-	-	-	-	1	-
HWB3	118	-	-	-	2	-	-	-
HWB4	4	-	-	-	2	-	2	-
HWB5	87	1	1	1	-	-	-	-
HWB6	18	-	4	-	2	2	3	1
Occurrence (%)	100	17	50	33	67	17	67	33
Density (#/m^2)	39.5	1	2.3	1.5	2.5	2	3.2	2

Table 16. The numbers and mean height ($\pm$ SE) of the three tallest balsam poplar seedlings and numbers of seedlings estimated to have been established in 2013, 2014, 2015 in each quadrat at the Hull's Wood Bar (HWB) study site along the Bow River in Fish Creek Provincial Park. The quadrat elevation above base river stage and inundation discharge are also shown.

Quadrat	Seedling by Estimated Establishment Year			Total Seedlings	Height (cm)	Elevation (m)	Inundation *Q* (m^3/s)
	2013	2014	2015				
HWB1	5	4	-	9	-	1.32	
HWB2	-	-	-	0	-	1.30	
HWB3	-	3	115	118	12.7	1.19	
HWB4	-	2	2	4	13.5	1.19	
HWB5	-	1	86	87	-	0.88	
HWB6	3	-	15	18	40.0	1.33	
Total	8	10	218	236			
Proportion	.03	.04	.92	1			

11. Carseland Weir Bypass (CWB)

Downstream of Calgary, the Bow River is joined by the Highwood River, which incorporates the inflow from the Sheep River. These two foothills rivers are undammed and naturally characterized by occasional major floods that persisted through the twentieth century (Rood et al. 1999). As described in the Introduction of this report, their dynamic inflow restores some of the hydrological, geomorphic and ecological dynamics along the Bow River (Rood et al. 1999).

Consequently, downstream from the Highwood inflow, the riparian woodlands along the Bow River were more complex prior to the 2013 flood. The prior floods of the Highwood River including the recent floods of 1995 and 2005 provided substantial erosion and sediment deposition and thus created suitable surfaces for the seedling colonization of balsam poplars and other native riparian plants. As a result, the woodland population included a broader range of tree and shrub ages and sizes, providing substantial structure, an ecological term for the vertical extent and variation that contribute habitat diversity, such as for birds and other woodland organisms.

Probably due partly to the recent and historic flow dynamics and flood events, and also probably due to the characteristic dynamics that preceded European settlement, the Bow River downstream from the Highwood River has a more complex channel form, with zones including multiple islands and braiding, with the occurrence of multiple channels that interweave along the floodplain zone (Figure 38, CWB1). Braiding is especially extensive upstream from the Carseland Weir, a concrete low-head dam that was constructed to provide an elevated pool to allow offstream water diversion from the south (river right) bank into the Bow River Irrigation District main canal. The weir blocks the main channel along the south bank and an earthen berm was constructed across the floodplain valley to the north, to constrain the flow into the dammed main channel (CWB2). Shortly downstream from the Carseland Weir, the Bow River naturally undertakes a change in channel form as the braided channels coalesce to for a single thread channel. This is the zone around Wyndham Carseland Provincial Park and provides a contrast in channel form from the braided channel segment upstream of the Carseland Weir.

The Carseland Weir zone is publicly accessible and has provided the take-out point for some of our prior riparian monitoring along the middle reach of the Bow River. That represents the segment between Bearspaw Dam and the Bassano Dam, below which the river naturally has a very different channel and bank form, and is naturally barren of riparian woodlands. Thus, as a complement to the Calgary Rivers Morphology Project, we are tracking riparian processes and woodlands in the zone around the Carseland weir and in Wyndham Carseland Provincial Park. We will limit our description of riparian conditions in this region but describe vegetation colonization as a comparative complement to that at the Carburn Park Island.

For this comparison, we particularly investigated riparian conditions and vegetation colonization through a zone that provided a bypass channel to the left of the Carseland Weir (Figure 38, CWB2), after the berm was eroded and breached by the flood flow. This reconnected the prior, natural channel, which had had limited flow that was provided by culvert drains under the berm. The berm breaching would have contributed substantial material but the finer particles had apparently been flushed downstream and the reconnected bypass channel has a surface with patches of alluvial sediments, including zones of sands, gravels and cobbles. It thus provides a mosaic of surface textures that are instructive relative to preferences for native and introduced riparian plants. The channel is flanked by a mature, and biodiverse balsam poplar woodland that would have provided abundant seeds of native shrubs and trees (CWB2). The broader zone has had periodic human disturbance as it provides a popular access and fishing area and there are various roadways and parking zones and these have brought in the regionally common introduced riparian plants. It is thus a useful study system with abundant seeds of native versus introduced plants and we emphasized the comparison of balsam poplar versus reed canarygrass colonization, with reference especially to the substrate sediment texture.

The zone immediately below the berm breach is especially heterogeneous, with patches ranging from very coarse cobbles and boulders to sand deposits (CWB3). The water regime is also diverse, with a culvert providing flow through the plant growth and thus providing wetter conditions while zones above and away are drier. Around the culvert channel and especially with coarser sediments, the riparian condition resembled that of the Carburn Park Island. There were abundant seedlings of a number of introduced plants species, providing a complex weed patch (CWB3). This suggests that very artificial sites with destructive erosion of artificial structures produce correspondingly non-natural riparian zones, which may favor encroachment of introduced plants, including weeds.

Down-channel the riparian system appeared more natural, with a broad, relatively flat low-elevation surface largely covered with gravels (CWB4). That extensive zone is being competitively colonized by native balsam poplars and sandbar willows as well as substantial seedling establishment of reed canarygrass (CWB4, 5). In addition to balsam poplar seedlings there are also some Jackii poplars, natural intersectional hybrids of *Populus balsamifera* x *P. deltoides*. The prairie cottonwood, *P. deltoides*, is the predominant native cottonwood downstream where the Bow and Oldman Rivers join to form the South Saskatchewan River (Brayshaw 1965; Rood et al. 1986; Floate 2004).

Along the transitional zones between the lower and relatively flat zone of scour and deposition and the woodland island, the intermediate elevations and sloping banks are covered primarily with reed canarygrass (CWB7). These zones have finer surface sediments and while there has been some seedling colonization by sandbar willow and balsam poplar, the reed canarygrass is predominant. If some balsam poplars survive the competitive juvenile phase, these would grow taller than the reed canarygrass, which is shade intolerant. It is thus possible that in some zones the balsam poplars may gain dominance but the conditions in 2015 suggest that these transitional would become bands of reed canarygrass. Related to this prediction, it is notable that the fringes of the islands upstream of the weir and berm are often characterized by dense reed canarygrass.

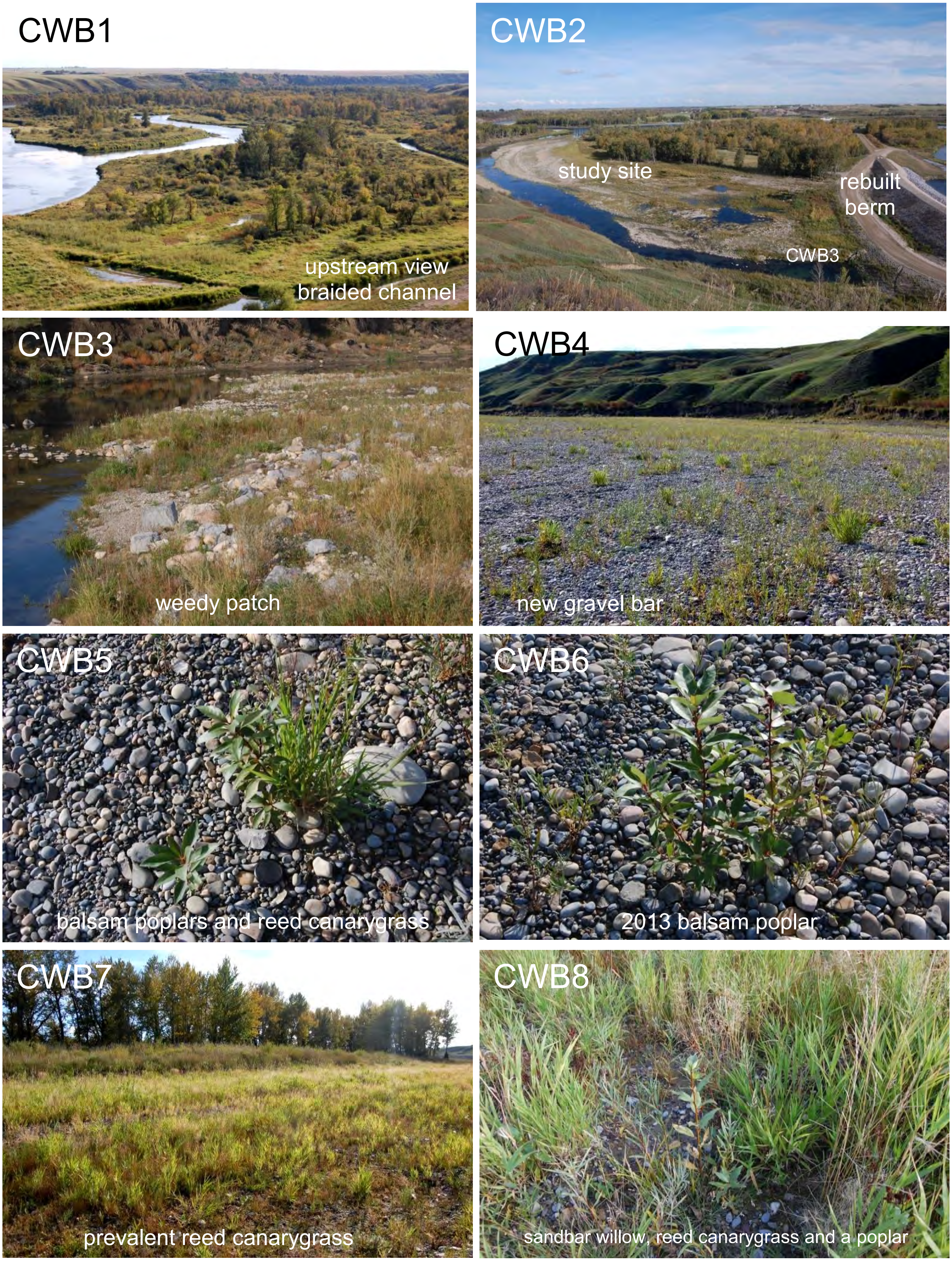


Figure 38. Ground level photographs taken at the Carseland Weir Bypass, Sept. 15, 2015.

12. Elbow Island Park (EIP)

The Elbow River is much smaller than the Bow River and through the developed zone from Sandy Beach to the outflow into the Bow River its banks are heavily developed, with homes and other buildings encroaching close to the river channel. The banks are heavily wooded with balsam poplars and a range of shrubs (Figure 40). There are commonly zones along the banks with various types of protection, including boulders, concrete and even wooden structures.

There are numerous bridges, including those for vehicles and pedestrians. Of these, the Mission Bridge, or 4th St. Bridge, is notable (Figure 39, Figure 40 EPI3, 4, 6). From upstream, the main flow is in a channel along the left bank (EPI2) and this flows below the arched bridge span near the left bank (EPI3, facing upstream). The bridge has three other arched spans, with the two middle spans being substantially smaller. A large, elongated island extends to and through the bridge, to continue as a smaller island extension downstream. This Elbow Park Island is heavily wooded, and includes white spruce (*Picea glauca*) as well as balsam poplars and a range of riparian shrubs. This vegetation composition and the sizes of the trees indicate that the island has been in place and stable for many decades. The woodland would choke off the middle two smaller spans (EPI4). A secondary channel extends to the right of the island (EPI5) and flows into the right span but this has substantial sediment deposition (EPI 6).

It would seem very likely that the extensive and heavily wooded Elbow Park Island would considerably impede conveyance of high flows of the Elbow River. This could be instructive relative to what might happen with the Bow River island below the 10th St. Bridge, with substantial woodland colonization. It would seem appropriate to restore the conveyance through the Mission St. Bridge and this would involve some woodland clearing and sediment excavation and removal.

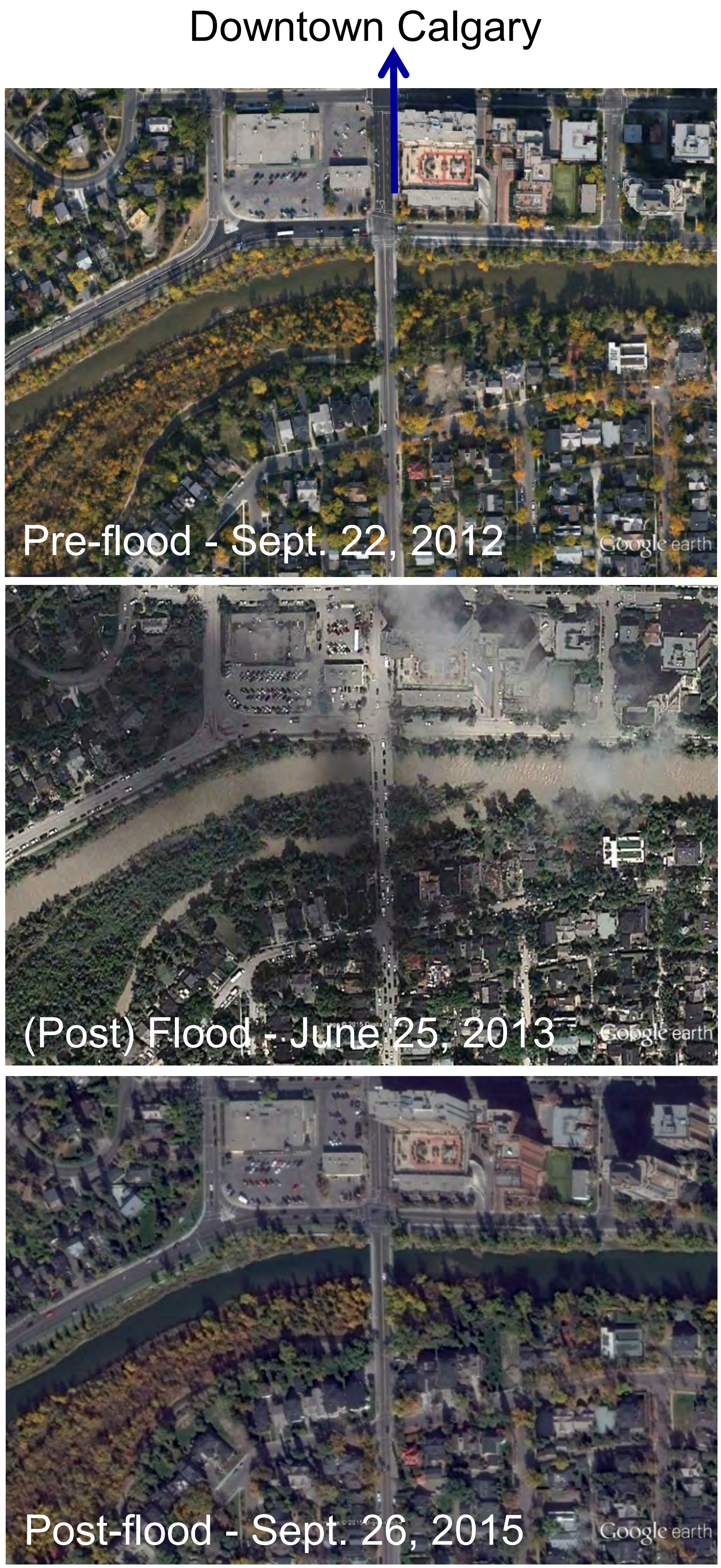


Figure 39. Aerial photographs of the 4th St. Bridge (Mission Bridge) spanning the Elbow River pre- and post- 2013 flood.

Figure 40. Ground level photographs of the Elbow Island Park (EIP) on Sept. 15, 2015.

Composite Analyses: Plant Species, Distributions and Elevations

We observed 34 plant species within the study quadrats or in adjacent zones on the bars and islands along the Bow River through Calgary. We provide Table 17 with the eight woody plants, the shrubs and trees; and then Table 18 with the 26 herbaceous (non-woody) species. These are sequenced by common names, along with their nativity (native versus introduced status), relevant life history traits, and their wetland status, which categorizes their occurrence relative to wetland zones and the moisture regime.

These are not exhaustive listings of the riparian plants along the Bow River. Instead, the tables present the primary species colonizing the barren bars and islands. Additionally, our analyses emphasized woody plants since these shrubs and trees would contribute to shrubland or woodland communities that would have greater influence on the bar and island stability and could impede river flood-waters. We have provided more thorough listings of the riparian plants in the literature review section of this Calgary Rivers Morphology Project, and that report section also describes their occurrences in transects rising away from the river edge and with maturing woodland communities.

For our present listing, the taxonomic treatment is in generally in accordance with USDA-Plants (http://plants.usda.gov/java/) and we provide common names as recognized by that North American standard source. We also provide alternative common names that are used locally and differing from the USDA-Plants treatment, we favor the taxonomic differentiation of *Salix exigua* from *S. interior* based on our consideration of their characteristics and distributions (Rood et al. 2011).

Woody Plants

Of the eight woody plant species (Table 17), the two poplars are large trees. Balsam poplar is the predominant tree along the Bow River and it provides the ecological foundation for the riparian woodland community. Consistent with its prevalence and our expectation, balsam poplar seedlings were abundant, occurring at all of the study sites and in three-quarters of the quadrats. It represented by far, the most abundant woody plant seedlings.

Jackii poplar is a native intersectional hybrid of the balsam poplar crossed with the prairie cottonwood, *P. deltoides*. The prairie cottonwood occurs naturally around ‘Bow Island’, the junction of the Bow and Oldman Rivers, which provides the commencement of the South Saskatchewan River. Prairie cottonwoods do not occur naturally in Calgary but they have been planted in Calgary, along with introduced Jackii poplar hybrids. While we observed the hybrid poplar seedlings, we did not observe prairie cottonwood seedlings at our study sites along the Bow River through Calgary.

Manitoba maple is a small tree that is referred to as boxelder in the United States. The tree is native in the southeast corner of Alberta and is abundant along creeks in that area and to the east. The abundant Manitoba maple provides the basis for the naming of Maple Creek, Saskatchewan, shortly east of the Alberta border. The tree is readily propagated and was planted in Calgary as an ornamental and a shelterbelt tree. It is notable that like the poplars and willows, this tree is dioecious, with separate male and female trees, and consequently, seed production requires individuals of both sexes. Some Manitoba maple seedlings were quite large, approaching a half m in height, such as along the bank margin of the Centre St. Bar. This tree thus grows rapidly and we expect expanding distribution of this naturalized tree. While not native, it occurs naturally only a short distance downstream and provides rich habitat for birds and other wildlife.

We commonly observed mature river birch at the sites and anticipate that seedlings that we observed were generally of this shrub. However, some could have been alder seedlings, which are difficult to differentiate as young seedlings. Chokecherry shrubs and seedlings were common and this shrub generally favors slightly drier sites than the other woody plants, except for wolf willow, which is a facultative riparian plant and thus occurs in upland zones as well as in riparian and transitional areas.

Herbaceous Plants

Since riparian zones are characterized by physical disturbance, these are particularly prone to invasion by non-native plant species. Of the 26 plants that we observed within the quadrats, 16 are introduced (Table 18). Three more species, including dandelion, have become naturalized across North America and are thus regarded as blending native and introduced status. Of the introduced species, four are regarded as noxious weeds, Canada thistle, leafy spurge, tansy and yellow toadflax. These are thus regarded as problem plants relative to agriculture, and either to crop production or within hay fields or pastures.

Of the herbaceous plants, we regard reed canarygrass as potentially the most serious threat to the ecological integrity of the riparian zones along the Bow River. This plant is native to Alberta, but there has been deliberate interbreeding and hybridization across distant genotypes and this has produced fast-growing hybrids that are highly invasive in western Canada. While the plant provides forage for livestock and wildlife, it forms dense mats in streamside zones and this excludes reproduction of the native cottonwoods (riparian poplars) and willows. We thus paid particular attention to reed canarygrass during the field studies.

Of the herbaceous plants, dandelion was most widespread in the study quadrats, followed by quackgrass and Canada thistle. However, the quadrat study was undertaken in mid- to late August and field observations in June and July revealed the prevalence of sweetclover with white or yellow flowers. That plant had senesced by mid-August and was thus underrepresented with our field inventory. Based on the June and July observations, this introduced plant would have probably been the most abundant herbaceous plant on the newly formed bars and islands. It is considered a noxious weed and does not exclude colonization by native species. It provides rich forage for livestock and wildlife and as a legume it fixes atmospheric nitrogen, probably contributing to the fertility of the riparian zones. We thus do not consider it a problem species.

Table 17. Woody plant species and their occurrences in study quadrats along the Bow River through Calgary.

Common Name	Species Name	Life history type	Wetland Status	Occurrence (% of quadrats)
Balsam poplar	*Populus balsamifera* L.	T	FAC	75.0
Chokecherry	*Prunus virginiana* L.	S	FAC	31.8
Gray Alder	*Alnus incana* (L.) Moench	S/T	FACW	6.8*
Jackii poplar	*Populus x jackii*	T	FAC	6.8
Manitoba maple (Boxelder)	*Acer negundo* L.	T	FACW	15.9
Sandbar willow	*Salix exigua* Nutt.	S	FACW	15.9
Wolf willow (Silverberry)	*Elaeagnus commutata* Bernh. ex Rydb.	S	FAC	-
River birch (Water birch)	*Betula occidentalis* Hook.	S/T	FACW	6.8*

*Seedlings of alder versus birch were ambiguous.

Life history type: Tree, Shrub
Wetland Status: Facultative, Facultative Wetland (explained in following table)

For following table:
I = Introduced; N = Native
*Life history: A = Annual; B = Biennial; G = Graminoid; H = Herb; P = Perennial; S = Shrub; T = Tree

**Noxious weed status determined from: Alberta Agriculture Weed Selector (http://www.agric.gov.ab.ca/app107/pestselector?type=Weed) and Royer, France, and Richard Dickinson (1999) Weeds of Canada and the northern United States: A guide for identification. University of Alberta.

***Wetland status abbreviations:
FAC = Facultative (occur in wetlands and non-wetlands); FACU = Facultative upland (usually occur in non-wetlands, but may occur in wetlands); FACW = Facultative wetland (usually occur in wetlands, but may occur in non-wetlands); UPL = Obligate upland (rarely occur in wetlands).

Table 18. Herbaceous plant species and their occurrences in study quadrats along the Bow River.

Common Name	Species Name	N/I Status*	Weed Status**	Life History Type*	Wetland Status***	Occurrence (% of quadrats)
Alfalfa	*Medicago sativa* L.	I	-	A/P H	UPL	6.8
Aster	*Aster sp.* L.	N	-	PH	-	9.1
Brittlestem hempnettle	*Galeopsis tetrahit* L.	I	Common	AH	FACU	-
Canada goldenrod	*Solidago altissima* L.	N	-	PH	FACU	-
Canada thistle	*Cirsium arvense* (L.) Scop.	I	Noxious	PH	-	27.3
Chickweed	*Cerastium arvense* L.	N/I	Common	PH	FACU	4.5
Curly dock	*Rumex crispus* L.	I	Common	PH	FAC	-
Dandelion	*Taraxacum officinale* F.H.Wigg.	N/I	Common	PH	FACU	47.7
Horsetail	*Equisetum arvense* L.	N	Common	PH	FAC	4.5
Foxtail barley	*Hordeum jubatum* L.	N	-	PG	FAC	2.3
Leafy spurge	*Euphorbia esula* L.	I	Noxious	PH	-	9.1
Narrowleaf dock	*Rumex stenophyllus* Ledeb.	I	Common	PH	FACW	6.8
Pineappleweed (Disc mayweed)	*Matricaria discoidea* DC.	I	Common	AH	FACU	9.1
Plantain	*Plantago major* L.	I	Common	PH	FAC	6.8
Prairie onion (Textile onion)	*Allium textile* A. Nelson & J.F. Macbr.	N	-	PH	-	2.3
Quackgrass	*Elymus repens* (L.) Gould	I	Common	PG	FAC	31.8
Reed canarygrass	*Phalaris arundinacea* L.	N	-	PG	FACW	20.5
Sage	*Artemisia absinthium* L.	I	Common	PH	-	2.3
Spreading yellowcress	*Rorippa sinuate* (Nutt.) Hitchc.	N	-	PH	FACW	-
Stinging nettle	*Urtica dioica* L.	I	Common	PH	FAC	4.5
Stinkweed(Field pennycress)	*Thlaspi arvense* L.	I	Common	AH	UPL	-
Sweetclover	*Melilotus officinalis* (L.) Lam.	I	Common	A/B/PH	FACU	4.5
Tansy	*Tanacetum vulgare* L.	I	Noxious	PH	FACU	2.3
White clover	*Trifolium repens* L.	I	Common	PH	FACU	11.4
Willowherb	*Epilobium montanum* L.	N/I	-	PH	-	4.5
Yellow toadflax	*Linaria vulgaris* Mill.	I	Noxious	PH	-	2.3

Proportional Occurrences

We have presented the quadrat results that reflect the patterns and variations in colonizing plants at the various study sites. The quadrat values are averaged to provide distributions as displayed in Figure 41. As shown, balsam poplars generally represented the most abundant seedlings and even at the Centre St. Bar, balsam poplars would have provided much greater biomass than the herbaceous species, due to their larger sizes. In an overview of that bar, balsam poplar are most prominent. Similarly, the overviews of the 10th St. Island and Glenmore Trail Bar also reveal the prevalent biomass of balsam poplar seedlings. After three growth seasons after the June 2013 flood, these had grown substantially and might be regarded as saplings.

The single study site at which balsam poplar was not the predominant plant was the Carburn Park Island. At that site various introduced plant species were prevalent, both in terms of plant numbers (Figure 41) and with the field observation, very probably by biomass. While a number of weedy species were abundant, as we indicated in the description of that study site, we expect that reed canarygrass will prevail over the other weeds and that the newly formed zones of that island will fairly rapidly develop into dense zones of reed canarygrass. As well as degrading the ecological values at that site, this would provide abundant seeds and vegetative propagules for further expansion by this problem plant. We consequently consider that some form of control for the Carburn Park Island would be appropriate.

Figure 42 displays the longitudinal, or downstream pattern with the various quadrats indicated. Note that this plotting is does not represent the spatial patterning since the multiple quadrats are plotted for particular sites and the sites are not evenly distributed along the downstream profile.

As shown, the upstream sites supported primarily poplars and other woody plant seedlings. At the Centre St. Bar, there were far more herbaceous plants, including common introduced plants. We were especially interested in the balance between balsam poplars versus reed canarygrass and there was an abrupt change for the sites downstream of the Centre St. Bar. We did not observe reed canarygrass in the quadrats or elsewhere on the upstream sites, and in contrast the problem plant was abundant at the Glenmore Trail Bar, and downstream (Figure 42). By biking along the Bow River we have surveyed other sections and believe that reed canarygrass particularly joins the riparian vegetation communities with the inflow from Nose Creek. That Creek is characterized by prolific reed canarygrass along its banks and this would provide a prolific source of seeds and clonal propagules. There might also be some contribution from the Elbow River and much more contribution from Fish Creek. Thus, while we observed no reed canary grass at the upstream sites, this plant occurred in almost all vegetated quadrats at the Carburn Park Island and at the Hull's Wood Bar. As we described, it was also abundant further downstream near the Carseland Weir.

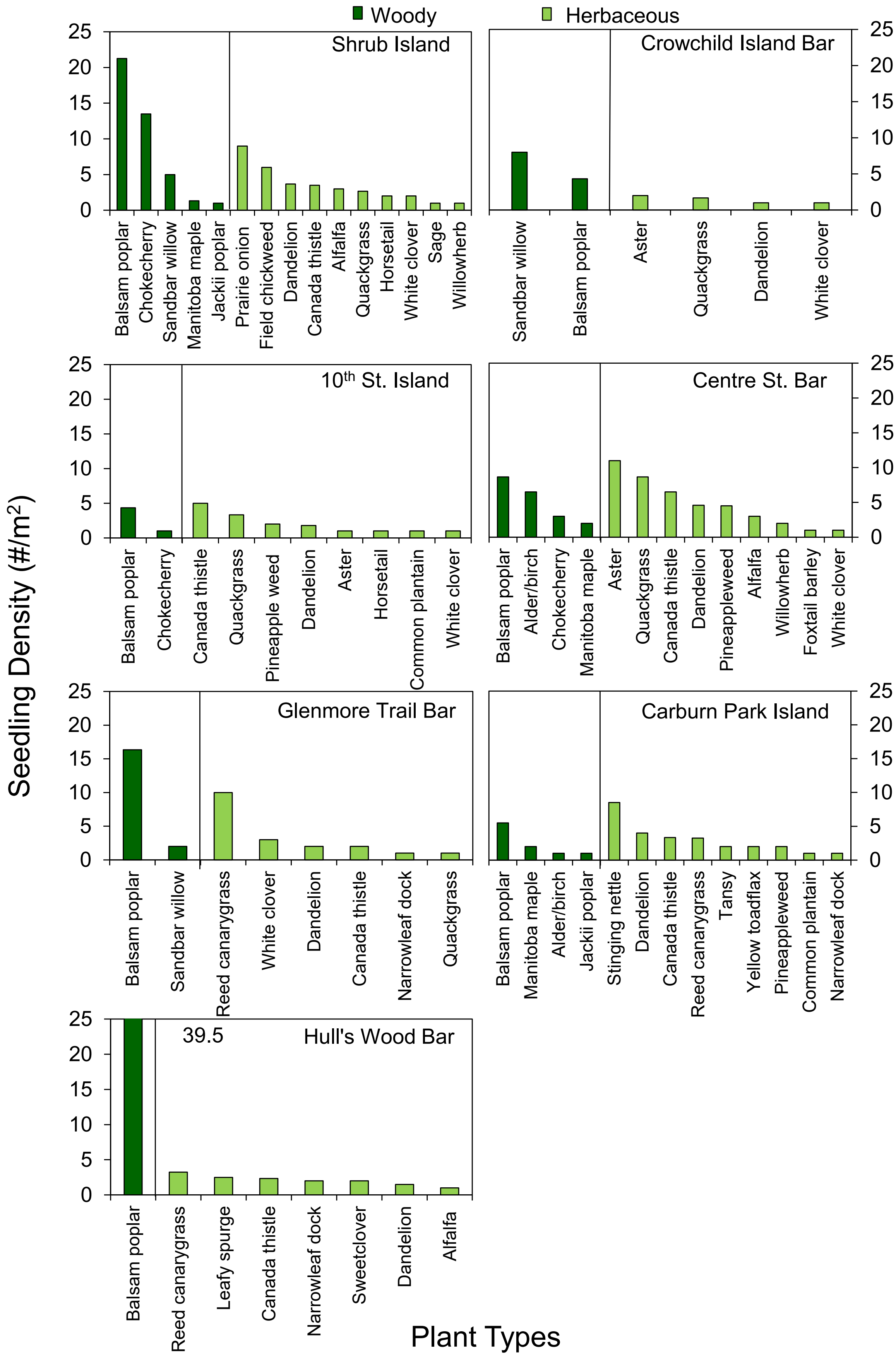


Figure 41. Woody and herbaceous seedling species densities at each study site along the Bow River.

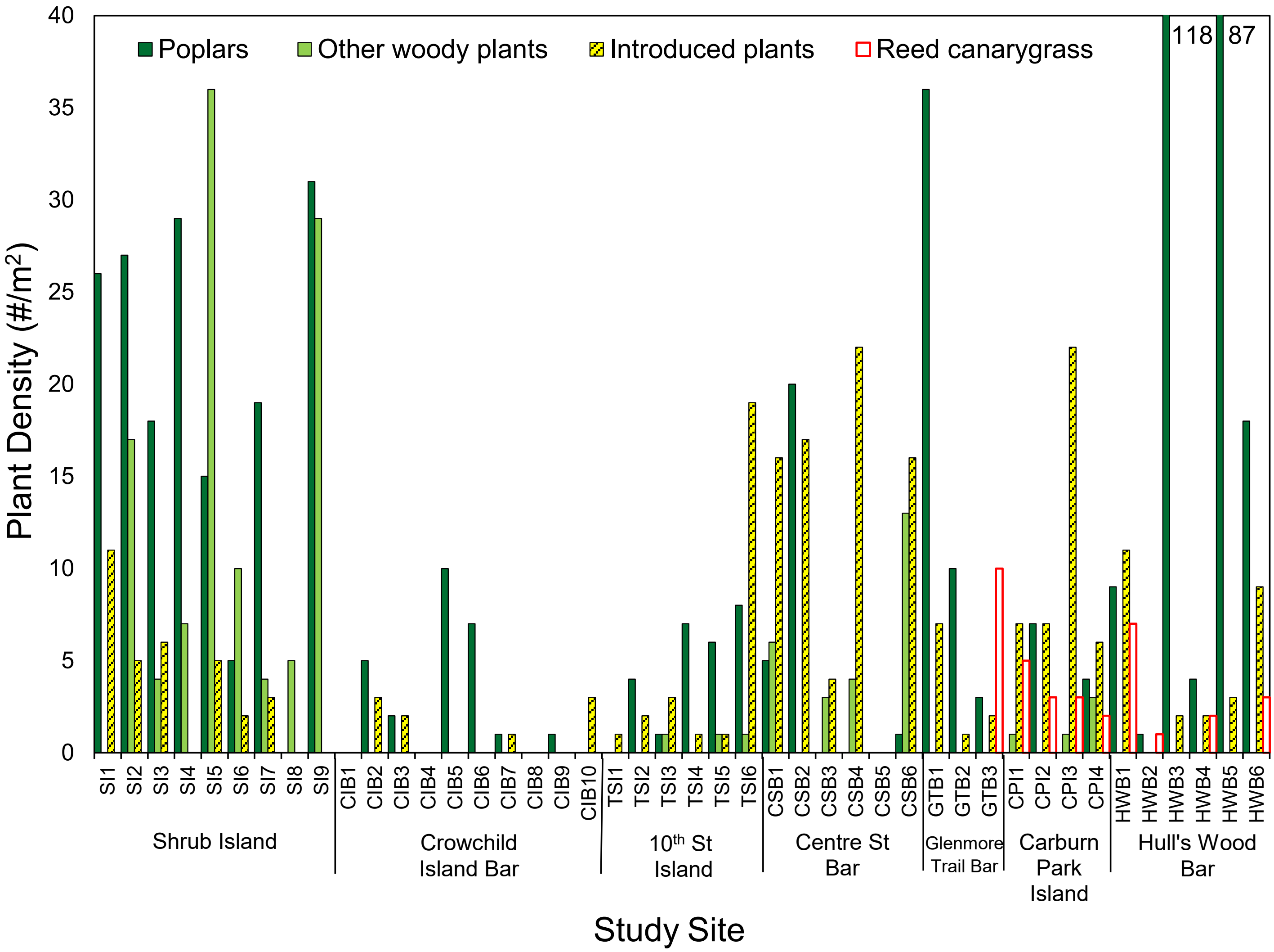


Figure 42. Poplars, woody, introduced, and reed canarygrass seedling densities in each study quadrat along the Bow River. Note that these are not equally spaced along the downstream length.

Seedling Elevations

An emphasis of our study was the analysis of the elevational patterns across the colonizing plant species. As we expected, there was a common elevational band and this extended from around 0.3 to 1.5 m above the base stage. Due to the flow augmentation (Figure 1), this base stage would be about 0.2 to 0.3 above the natural low stage at the end of the plant growth season. With this adjustment, the colonization band would thus be from about 0.5 to 1.7 m above the natural base stage. This recruitment band is very similar to the recruitment elevations that have been determined from various other studies along other Alberta rivers and other rivers across Western North America (Mahoney and Rood 1998).

Relative to the recruitment band, we expected more differentiation across the different plant types than we observed (Figure 43). This may be more readily compared with separate plots for the plants types, as indicated in Figure 44. As shown, balsam poplar seedlings occurred from 0. 2 to 1.9 m above the augmented base stage, and were more abundant from ~ 0.4 to 1.3 m. Other woody plans displayed a narrower recruitment band, primarily from 0.2 to 0.7 m above the base stage. This included different species, and we might have expected this diversity to broaden the band.

The introduced plants are often weedy and thus ecological generalists, tolerating a broader range of physical environmental conditions. Consistent with this, these occurred across a broad elevation band, with less evidence of preferential elevation than for the other woody plants (Figure 44). This again involves a blending of different species and this would contribute to the elevational range.

We had expected that reed canarygrass might particularly colonize lower elevational surfaces. This was the case for the plants at the Carburn Park Island but the new seedlings at Hull's Wood were almost one m higher is relative elevation (Figure 44). Since reed canarygrass was only observed at the downstream sites, there was more limited sampling and conclusions about its elevational preferences are correspondingly limited. Recognizing this limitation, the overall field occurrences suggest that reed canarygrass may colonize as broad a range of elevations as balsam poplar. Conversely, there was fairly discrete banding of the lower reed canarygrass versus a broader, higher band of balsam poplars at the Glenmore Trail Bar and we observed similar differentiation at some other, non-inventoried locations.

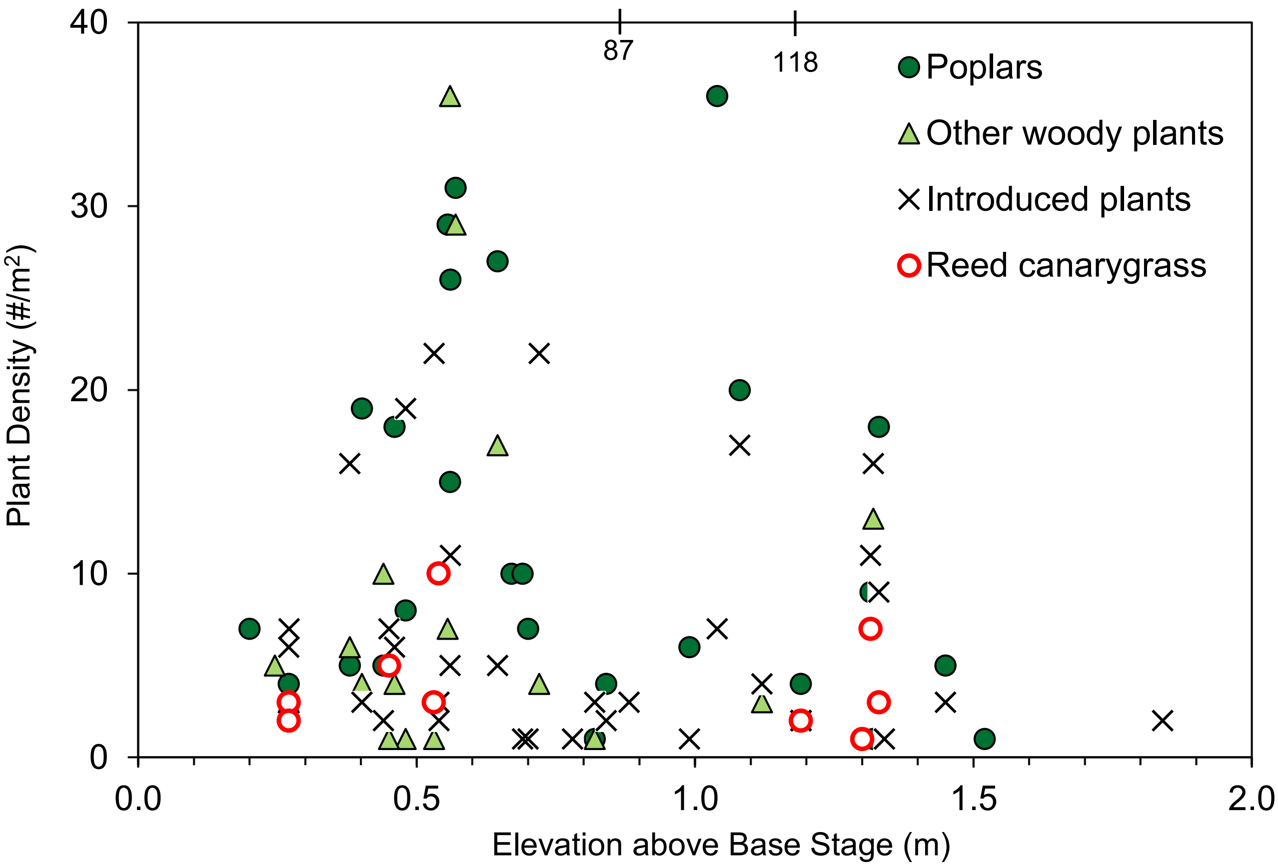


Figure 43. Densities of poplars, other woody plants, introduced plants, and reed canarygrass versus elevation above the base stage, with results by quadrat for sites along the Bow River.

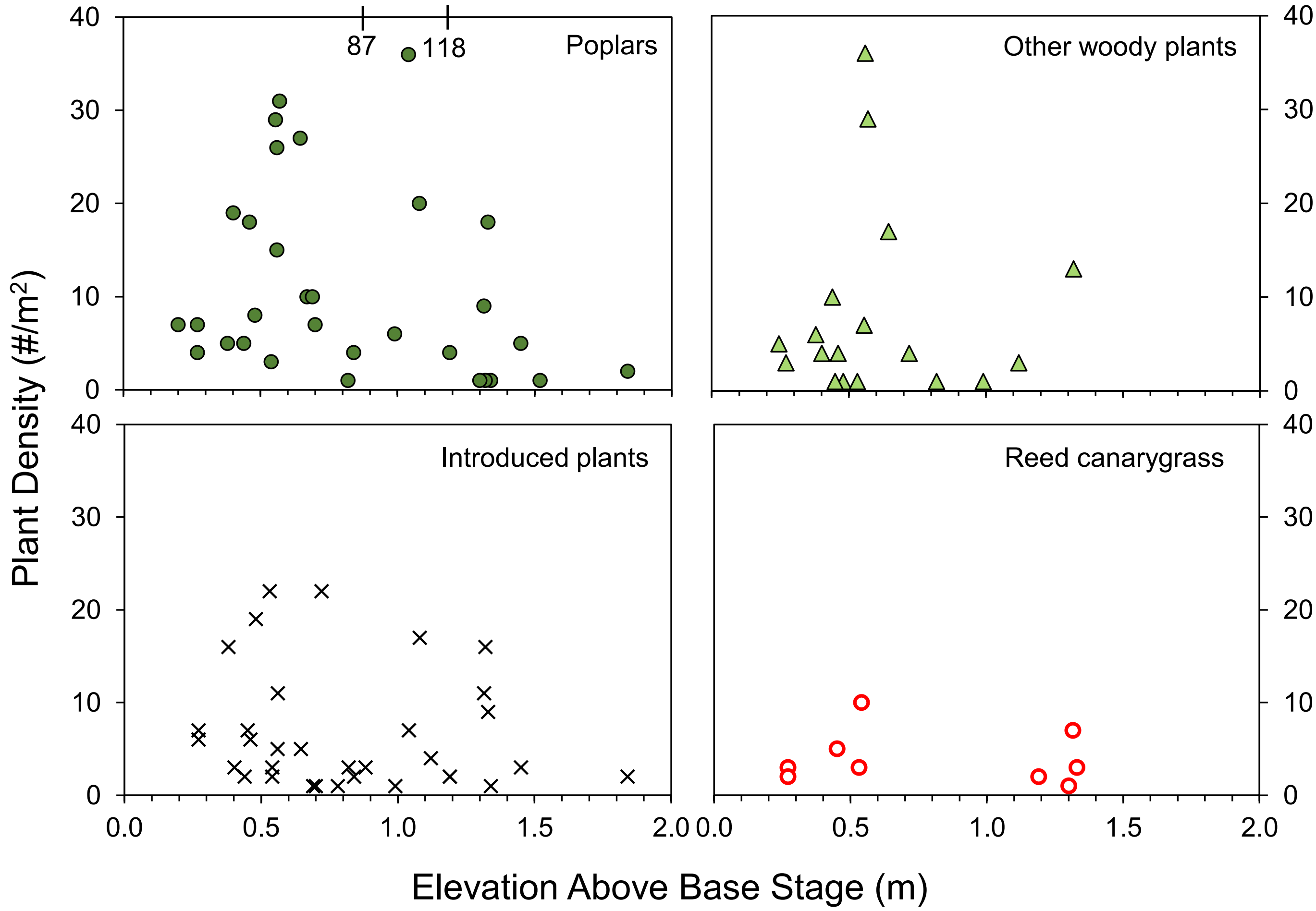


Figure 44. Densities of poplars, other woody plants, introduced plants, and reed canarygrass versus elevation above the base stage for quadrats at study sites along the Bow River.

Sediment Texture

Our sampling of sediment particle sizes was limited, with only nine values per quadrat. These were combined to provide a distribution for each site but this was still limited. We have also taken photographs of the surfaces and this could be used for digital image analysis to provide further particle sizes. Recognizing the limited numbers, the distributions did provide continuous plots that are tightly fit with polynomial functions and are consequently probably sufficient for a semi-quantitative comparison across the priority sites.

Cumulative distributions of the particle sizes are plotted for four upstream sites in Figure 45. As indicated, the particle distributions were quite similar on Shrub Island and the Centre St. Bar. These had higher proportions of sands and then predominantly coarse gravels to small cobbles. The Crowchild Island Bar was more homogeneous, lacking sand and then having predominately coarse gravels. The 10th St. Island was also relatively homogeneous but with very coarse gravels to small boulders.

We subsequently provided smoothed distributions fit with polynomials that allowed for the determination of the common particle size distribution thresholds (Figures 46 to 52). Note that our analysis did not involve ‘binning’, or the clustering of values with ‘larger than’ thresholds that is commonly applied to results from a gravelometer. We chose not to use that method since our initial observations indicated very coarse sediments with relatively homogeneous distributions. This reflects the extensive upstream damming and particularly the short distance below Bearspaw Dam, along with the extensive bank stabilization through this urban corridor.

Along the Bow River through Calgary, the surface sediment textures become progressively finer downstream (Figure 53). Figure 53 provides the derived mean sediment particle sizes, with averaging of the $\log_2$ values, to account for the exponential variation and to lessen the influence of very large particles. This plot also displays the substantial variation across the different quadrats at particular sites.

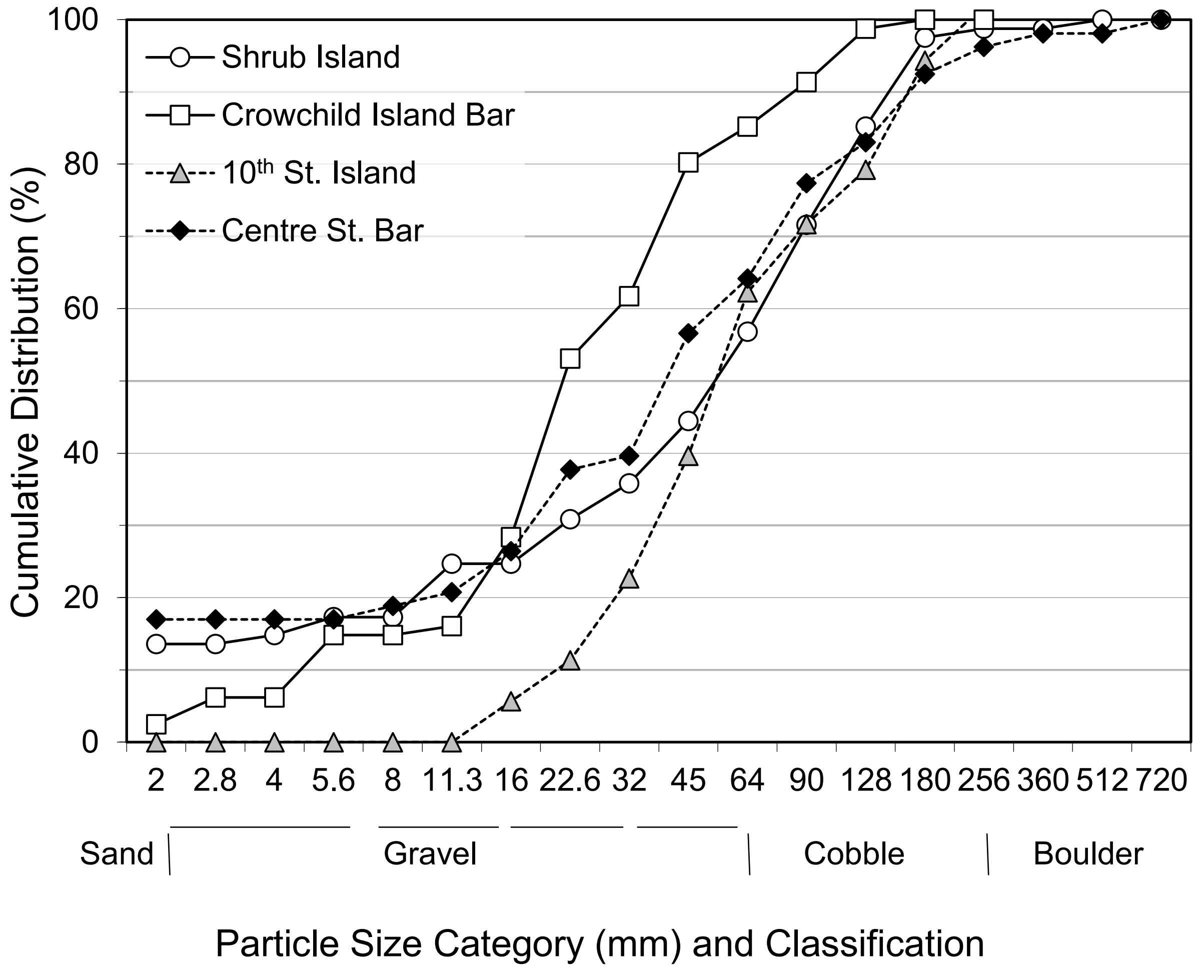
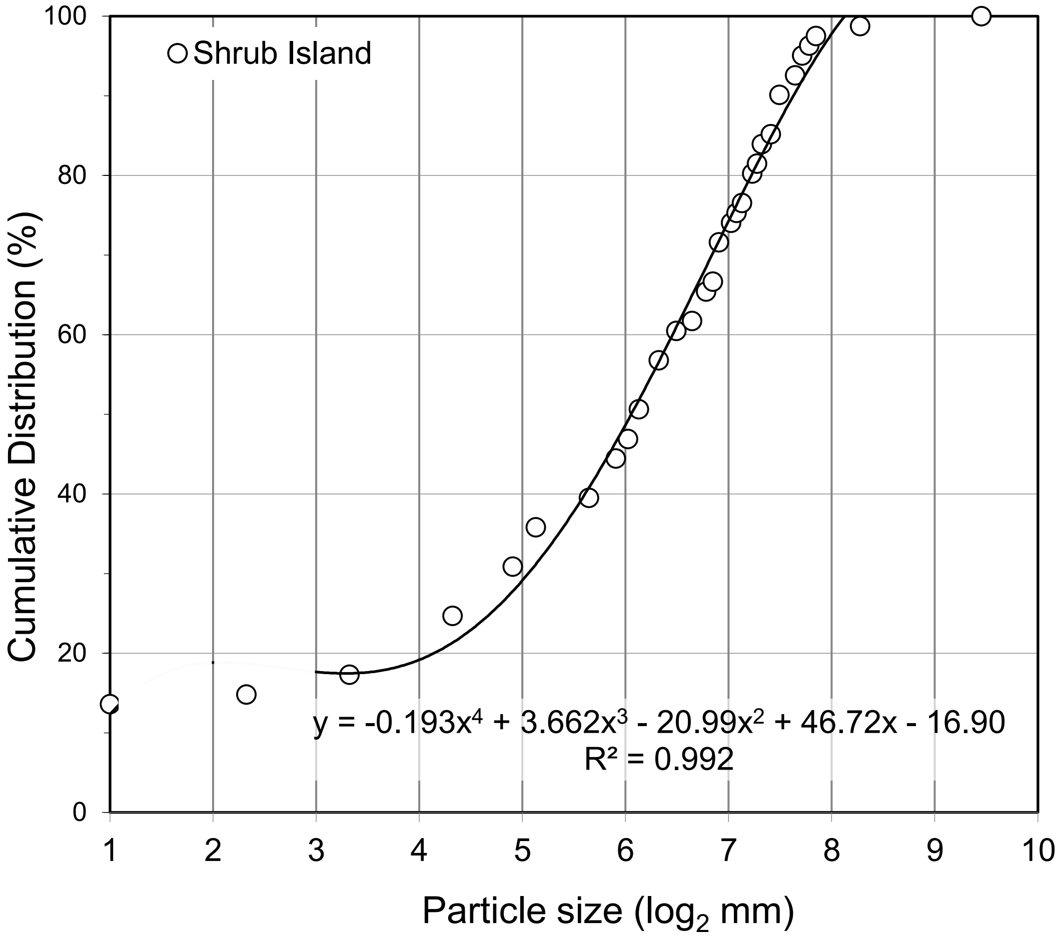
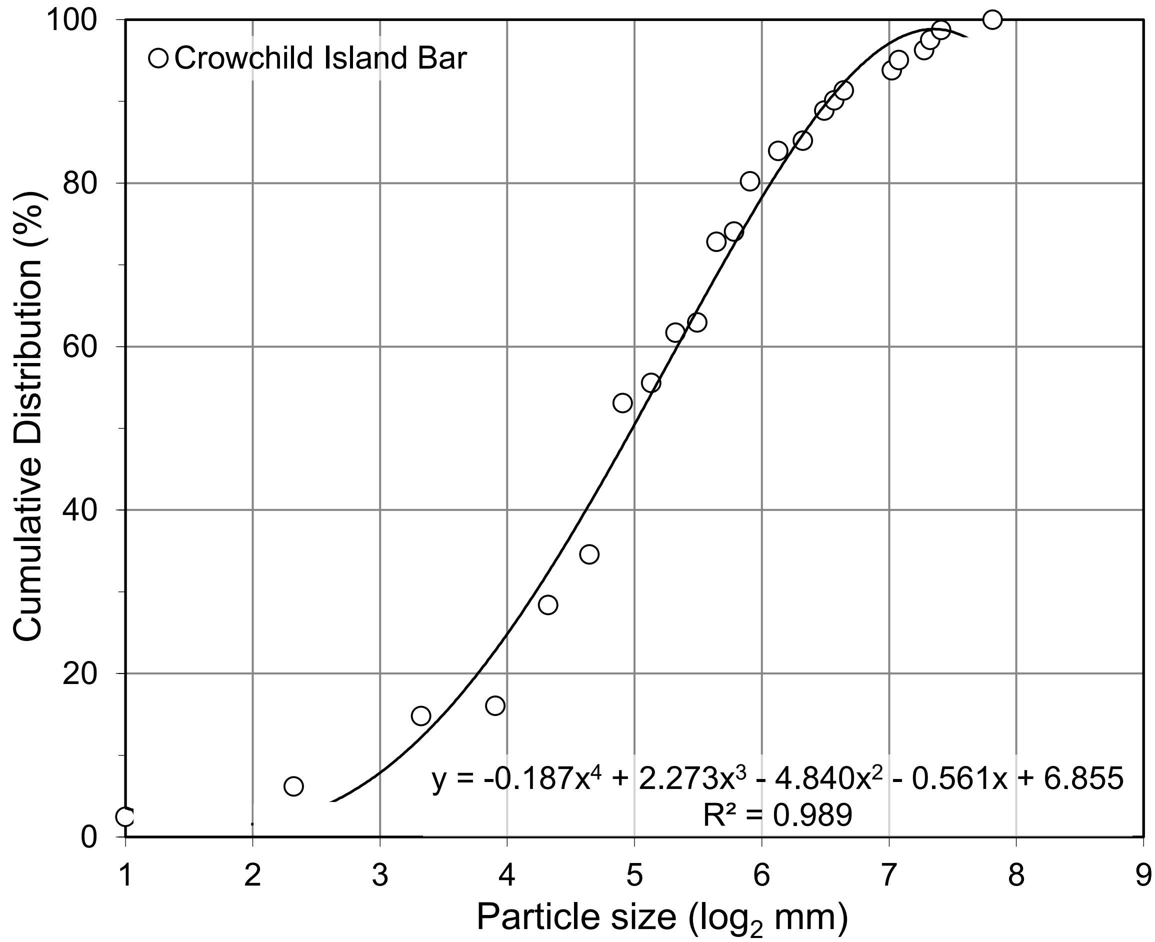


Figure 45. Distribution of sediment sizes at four study sites along the Bow River through Calgary.



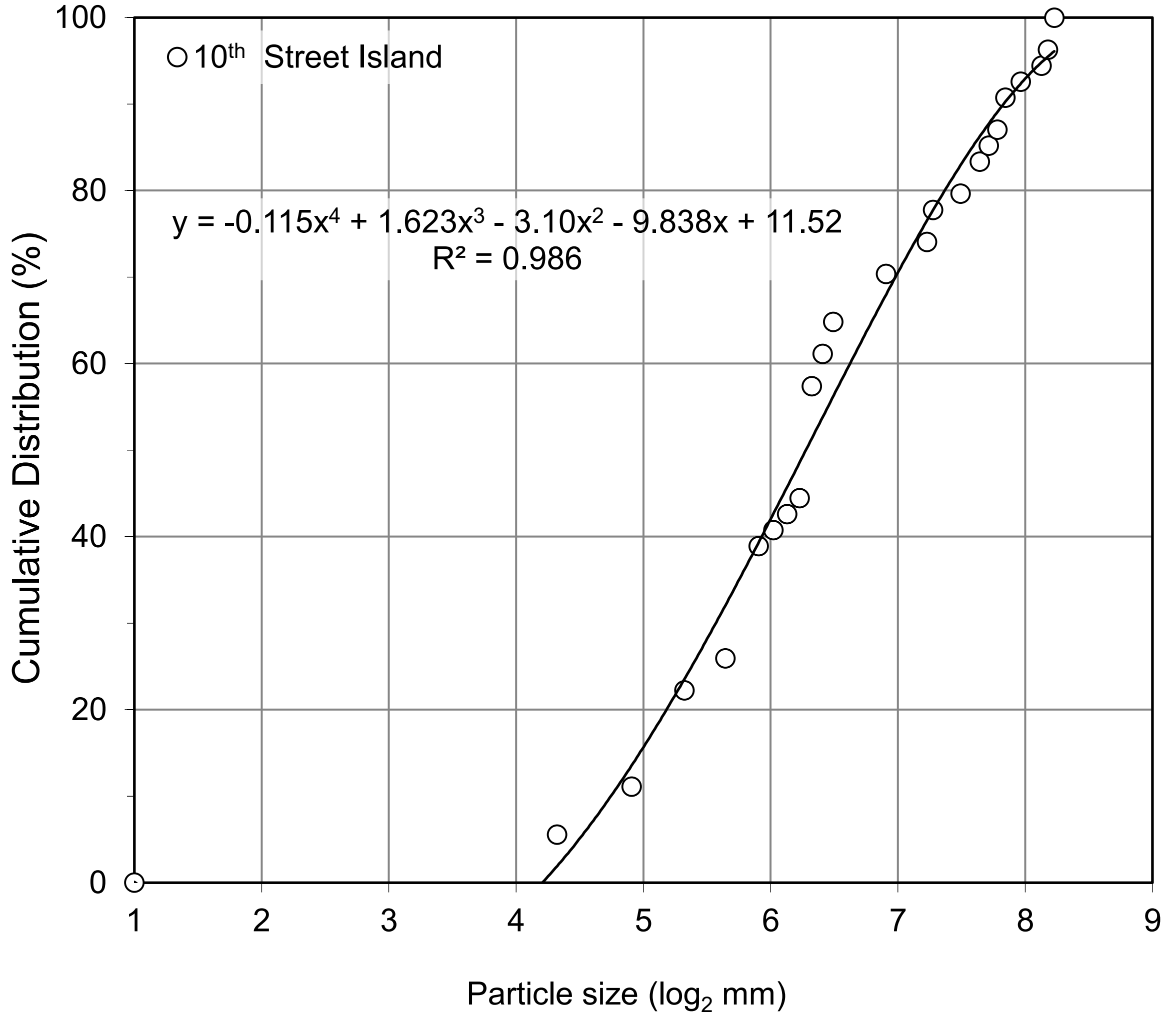
Class	log_2 mm	mm
D16	1.3	2.5
D25	4.7	25.8
D50	6.1	66.7
D75	7.0	130
D84	7.4	165
Heterogeneity	2.3	104

Figure 46. The cumulative distribution of sediment particle sizes at the Shrub Island study site in the Bow River, Calgary, AB.



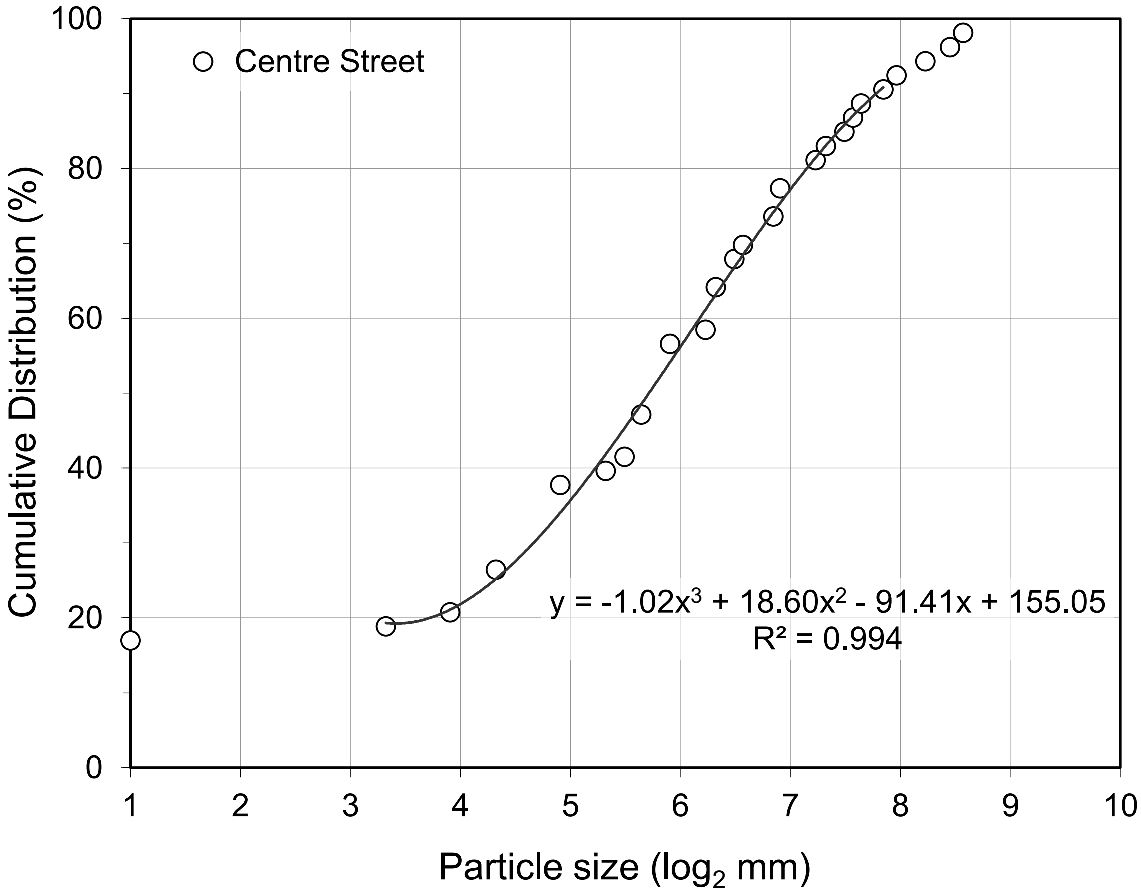
Class	$\log_2$ mm	mm
D16	3.6	11.7
D25	4.0	16.0
D50	5.0	31.6
D75	5.9	58.9
D84	6.2	75.6
Heterogeneity	1.9	42.9

Figure 47. The cumulative distribution of sediment particle sizes at the Crowchild Island Bar study site along the Bow River, Calgary, AB.



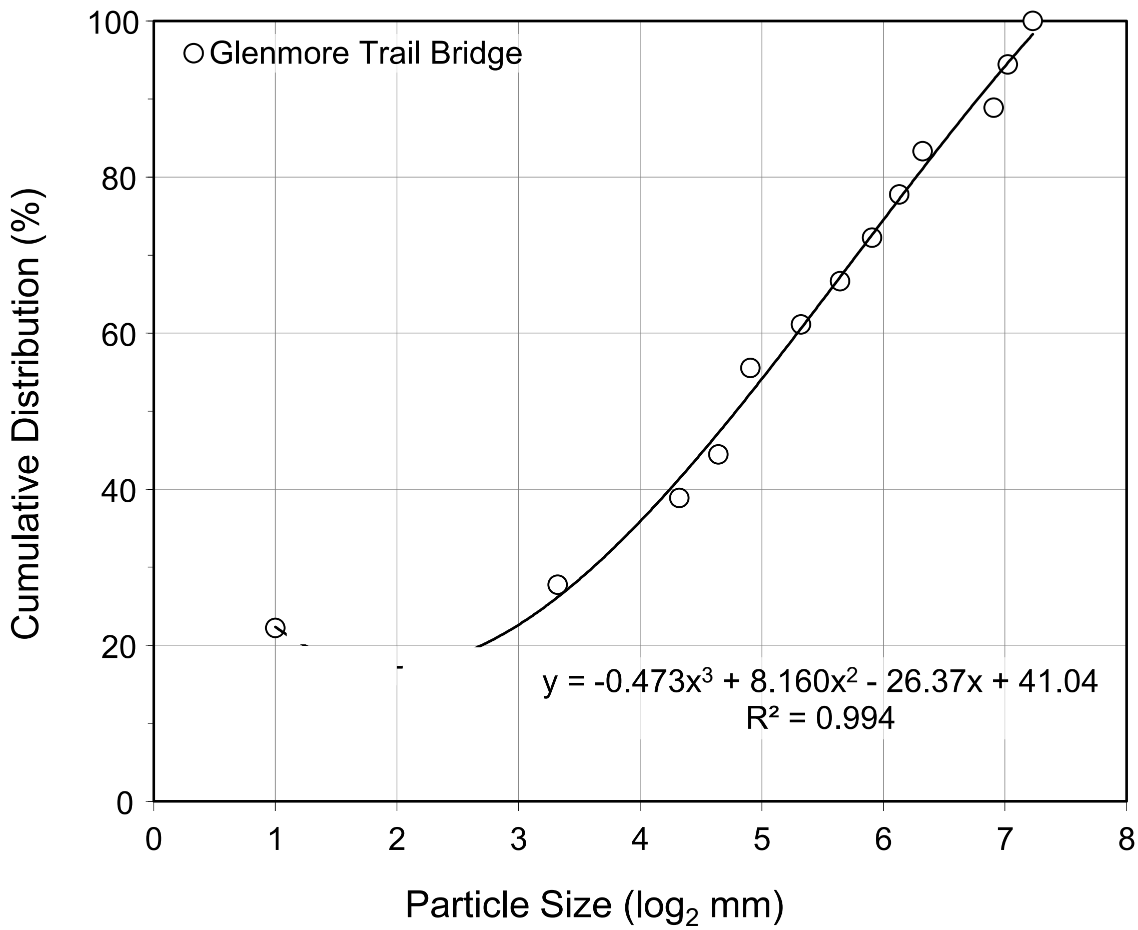
Class	$\log_2$ mm	mm
D16	5.0	32.2
D25	5.3	40.5
D50	6.3	77.7
D75	7.2	144
D84	7.5	186
Heterogeneity	1.8	104

Figure 48. The cumulative distribution of sediment particle sizes at the 10th Street Island study site in the Bow River, Calgary, AB.



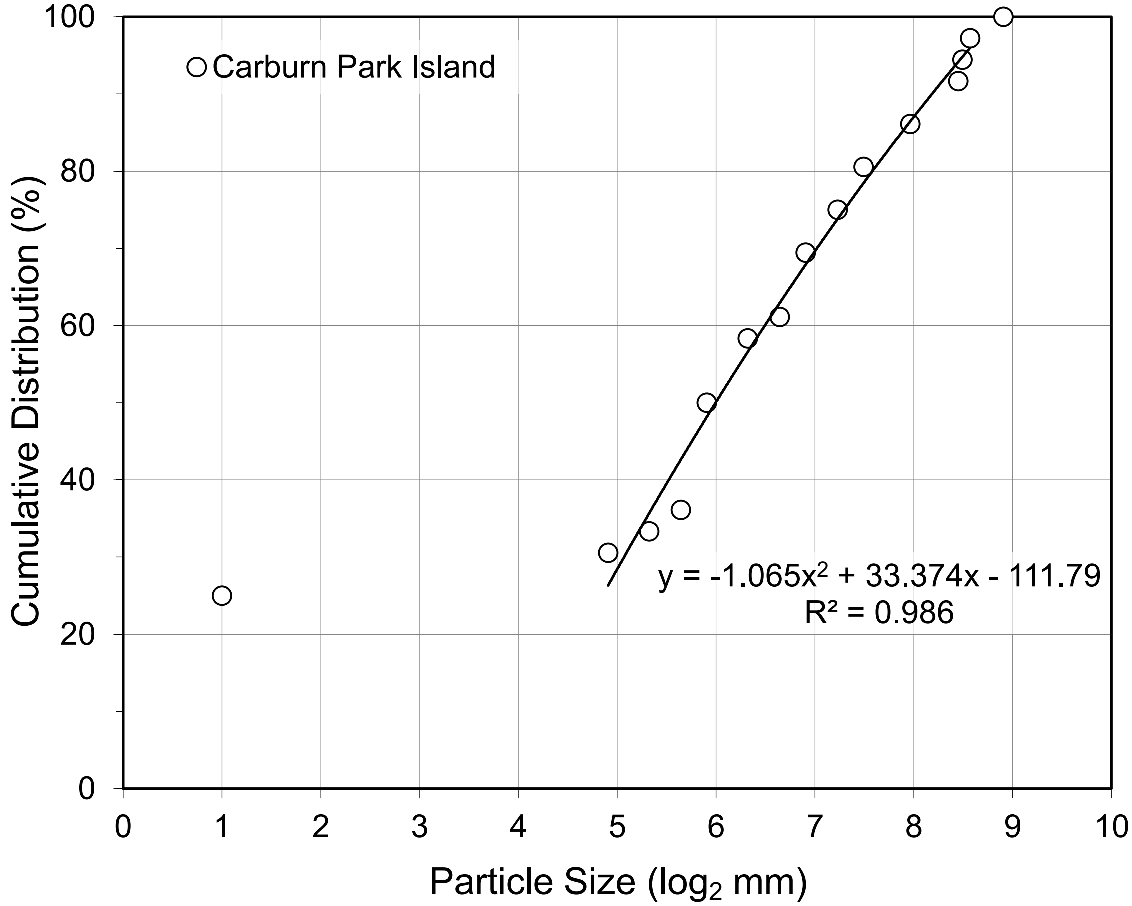
Category	$\log_2$ mm	mm
D16	1.0	< 2.0
D25	4.31	19.8
D50	5.71	52.3
D75	6.89	119
D84	7.38	167
Heterogeneity	2.58	98.8

Figure 49. The cumulative distribution of sediment particle sizes at the Centre Street Bar study site along the Bow River, Calgary, AB.



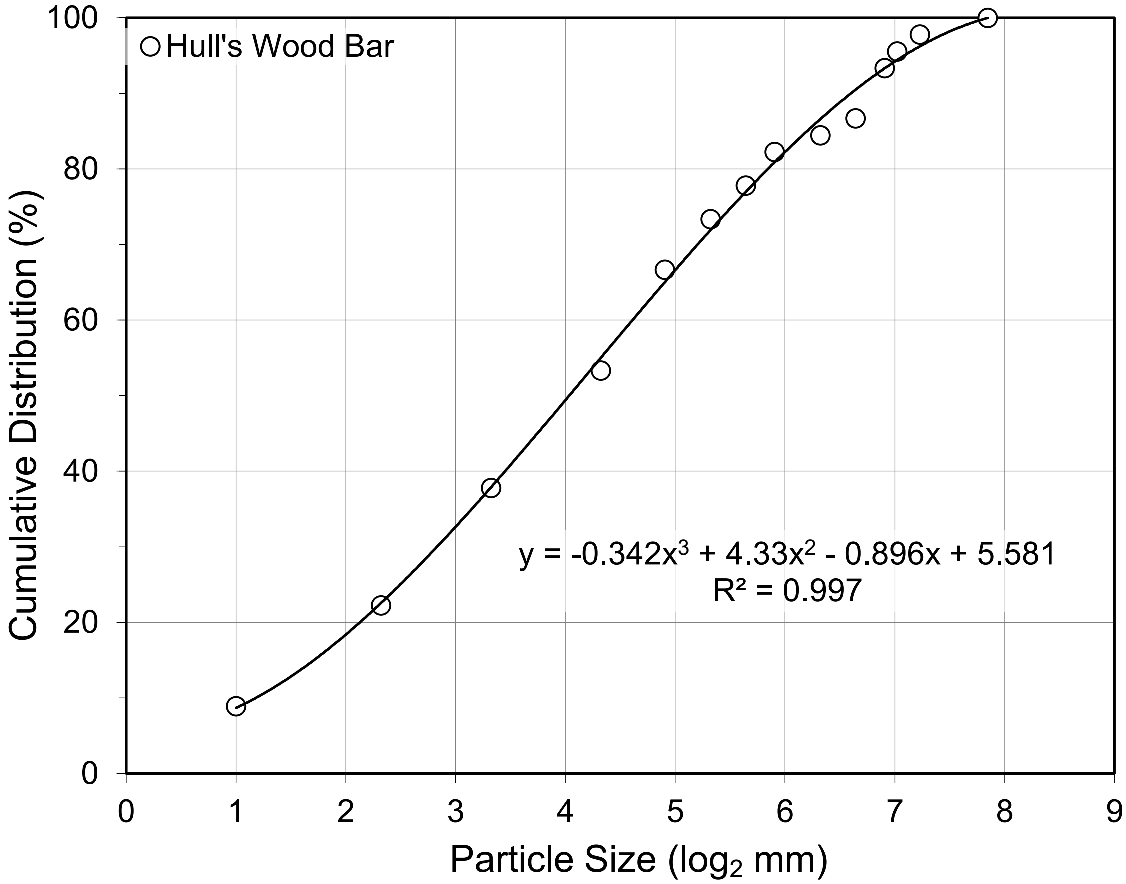
Category	$\log_2$ mm	mm
D16	1.0	2.0
D25	3.2	9.3
D50	4.8	27.7
D75	6.1	66.3
D84	6.5	91.8
Heterogeneity	2.8	56.9

Figure 50. The cumulative distribution of sediment particle sizes at the Glenmore Trail Bridge study site on the Bow River, Calgary, AB.



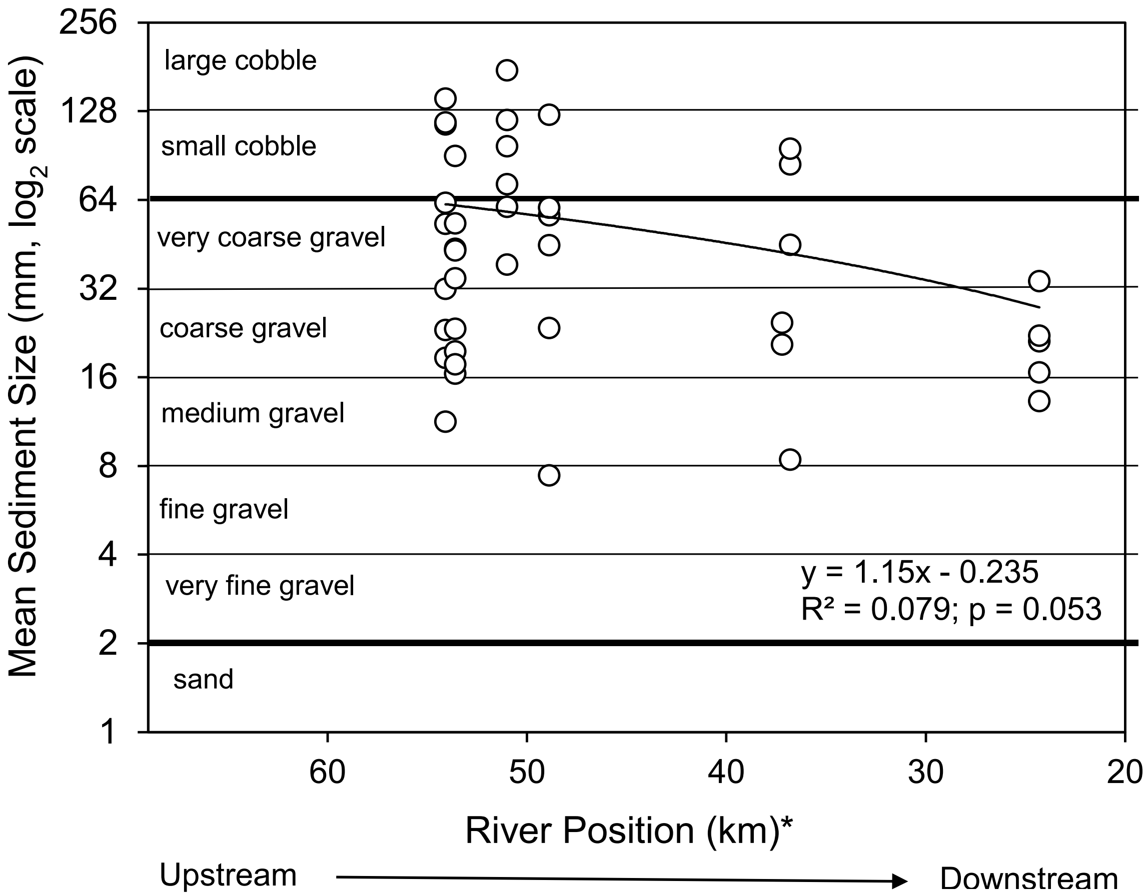
Category	$\log_2$ mm	mm
D16	1.0	2.0
D25	4.9	28.8
D50	6.0	63.6
D75	7.3	158
D84	7.9	236
Heterogeneity	2.5	129

Figure 51. The cumulative distribution of sediment particle sizes at the Carburn Park Island study site on the Bow River, Calgary, AB.



Category	$\log_2$ mm	mm
D16	1.8	3.5
D25	2.5	5.7
D50	4.0	16.4
D75	5.5	45.9
D84	6.1	69.6
Heterogeneity	3.0	40.2

Figure 52. The cumulative distribution of the sediment particle size at the Hull's Wood Bar study site on the Bow River, Calgary, AB.



* River position was measured upstream from the Highwood inflow.

Figure 53. Distribution of sediment particle sizes along the Bow River from upstream to downstream. These are derived means, with log_2 transformations, averaging and then back conversion (2^n).

Correspondences between Environmental Characteristics and Vegetation

Those analyses of sediment texture by quadrat were considered along with other site and quadrat-based characteristics to consider patterns of colonizing vegetation (Table 19). For this analysis, we considered the river distance extending downstream from the Bearspaw Dam, rather than upstream from the Highwood River inflow. Thus, a positive correlation coefficient represents an increase downstream.

With the correlation table (Table 19), there are some redundant measures across different characteristics. Most substantially, poplars provided the most common and abundant seedlings and consequently there were very strong correspondences between the seedling densities of poplars, woody seedlings and total seedlings (middle of diagonal listing: 0.931, 0.883 and 0.941).

For the other, more independent characteristics there were a number of trends, apparent statistical patterns ($p < 0.1$), and a few significant associations ($p < 0.05$) (Table 19). Relative to vegetation, there were increasing densities of poplar, reed canarygrass and total seedlings downstream. Thus, the downstream sites often had more extensive vegetation colonization. This pattern would probably be strengthened if we had undertaken quadrats at the Bowmont Park site, since there was minimal seedling colonization on the barren area at the upstream zones of the island and bars at that site.

Species richness indicates the number of different plant species and thus provides one important measure of biodiversity. In contrast to our expectation, richness increased with increasing surface sediment size (Figure 54). This association was displayed across some sites and within some sites, including the relatively natural Shrub Island and the very non-natural Carburn Park Island. There were thus some quadrats with very coarse gravel and small cobble, which supported seven or more different plant species. Especially at the Carburn Park site, the surface substrate included coarse sediments and also fine sand that was sifted in between the larger sediments and upon which the seedlings actually grew. A more extensive analysis could consider surface sediment blends as well as sub-surface materials and there could be more insight into the preferences of seedling establishment. But our observations were clear in revealing substantial seedling colonization on very coarse surfaces indicating that there was not a requirement for finer sediments for substantial seedling colonization on the newly formed or expanded bars and islands along the Bow River.

The other observed correlation involved vegetation characteristics and particularly, increasing abundance or density of introduced plants with increasing species richness. This would be expected since two-thirds of the observed herbaceous plant species are introduced, or non-native to this region. Thus, with weedier sites such as at Carburn Park there would be the combination of increasing richness (more species) and more seedlings of the introduced species.

There were relatively few significant correlations across the environmental and vegetation variables and we had anticipated stronger correspondences. These results reveal substantial variation within and across the sites and this variation diminishes the prospect for a clearly defined hydrogeomorphic model that would characterize the physical requirements for colonization by the different plant species. This would subsequently reduce the effectiveness of our initially proposed strategy to project colonization across the new surfaces based primarily on the combination of elevation and sediment texture. Instead, these results suggest the key importance of seed availability. This is especially demonstrated by the occurrence of reed canarygrass downstream from Nose Creek, and also by the prevalence of Manitoba maple at sites with established trees on the adjacent banks. We might thus conclude that the new zones would be extensively colonized by balsam poplars, along with whatever other riparian plants are nearby.

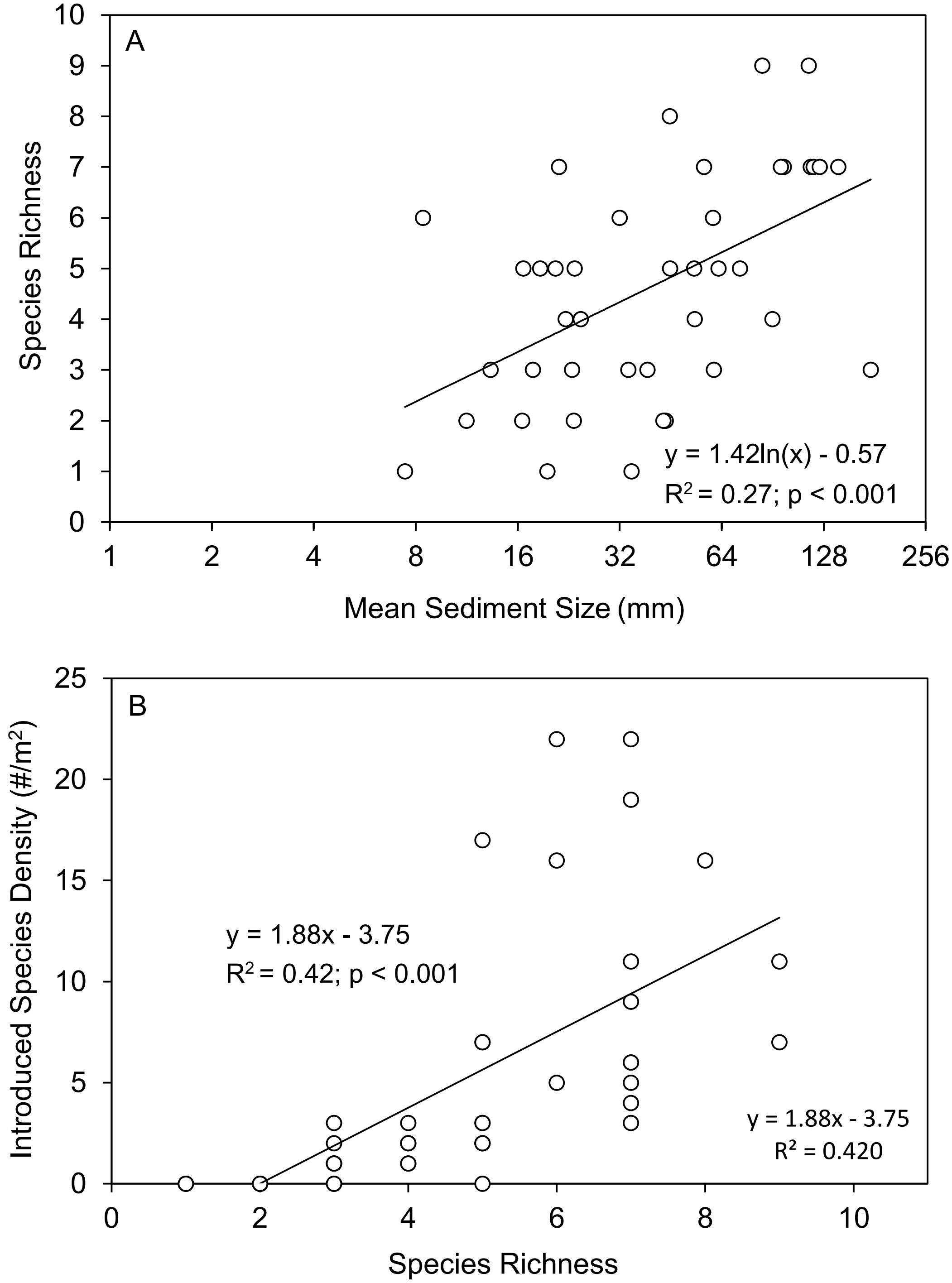


Figure 54. (A) Association between species richness versus mean sediment size (derived, Figure 52), and (B) association between density of introduced species versus total species richness for riparian study quadrats along the Bow River through Calgary.

Table 19. Correlations between physical characteristics (quadrat elevation and sediment texture) and seedling densities (#/m^2). Statistical associations are in bold font: * = $p < 0.05$; t = $p < 0.1$.

	Quadrat elevation (m)	Mean sediment size (log_2)	Species richness	Total seedlings	Woody seedlings	Poplar seedlings	Willow seedlings	Other woody seedlings	Introduced seedlings	Reed canarygrass seedlings
River distance from Bearspaw Dam	**0.257**^{t}	**-0.304**^{t}	0.193	**0.302***	**0.256**^{t}	**0.388***	**-0.254**^{t}	**-0.279**^{t}	0.139	**0.531***
Quadrat elevation		0.007	-0.176	-0.098	-0.045	0.073	-0.138	-0.231	-0.082	-0.028
Mean sediment size (log_2)			**0.520***	-0.135	-0.206	-0.247	-0.028	0.029	0.174	-0.115
Species richness				**0.352***	0.089	0.052	**-0.253**^{t}	0.215	**0.648***	0.243
Total seedlings					**0.931***	**0.883***	-0.041	**0.288**^{t}	0.246	-0.082
Woody seedlings						**0.941***	0.033	**0.277**^{t}	-0.067	-0.187
Poplar seedlings							-0.084	0.078	-0.056	-0.132
Willow seedlings								-0.033	-0.204	-0.154
Other woody seedlings									0.029	-0.160
Introduced seedlings										0.145

Projecting Riparian Vegetation Colonization - 'Camo-maps'

While our analyses of the quadrat-specific environmental characteristics were less productive than we had expected, two other aspects substantially benefited the predictive mapping of the likely colonization of riparian shrublands and especially, woodlands. First, the extensive resource of post-flood aerial photographs allowed for site-specific inundation mapping. This would accurately reveal the zones on the bars or islands that were inundated by particular river flows. Second, the finding that reed canarygrass was absent from the upstream sites eliminated that prospective component. Based on the observation of riparian zones along the Bow River downstream from Calgary and after the 1995 and 2005 floods that extended from Highwood River inflows, we anticipated that the major challenge would be determining whether the riparian fate would be a new or rejuvenated woodland following balsam poplar colonization, versus a zone of reed canarygrass that would exclude further colonization by the native poplars and willows. Since our upstream sites had no reed canarygrass, the encroachment by that invasive plant would probably not be a factor upstream of Nose Creek.

Our projection of colonization and subsequent development into woodlands with balsam poplars or shrublands with willows and other shrubs commenced with a foundational principle of river science, the prominent occurrence of the 'Ordinary High Water Line' (OHWL; USACE 2005). This commonly involves a fairly obvious and abrupt change in the condition along the river shoreline and provides the basis for legal considerations such as related to ownership and access. This concept is applied to coastal as well as stream shorelines but complexities exist since these shorelines are naturally dynamic and the positions of the OHWL thus change over time. Along gradual river banks with perennial woody riparian vegetation, the OHWL may represent the limit of the riparian shrubs and trees and the transition to a relatively barren zone that is almost annually inundated.

With the regulated flow regime, the OHWL is prominent along many river shorelines of the Bow River through Calgary. Barren, exposed gravel bars occur below the OHWL, and an abrupt transition occurs at the OHWL to provide dense perennially vegetation above (Figure 55). Along these simplified channel positions, vegetation below the OHWL may be limited to ruderal annual plants, species that are often introduced or weedy and rapidly establish on the barren surfaces. Along the Bow River, sweetclover is especially prominent in the periodically inundated parafluvial or varial zone below the OHWL.

With more natural and more dynamic flow regimes along other rivers there is often elevational banding above the OHWL, but this is more limited along the Bow River as there is often an abrupt transition to shrubland or woodland, with a number of woody riparian plant species. With a more natural flow regime, there would generally be elevational banding with obligate wetland species favoring the lower positions and then facultative wetland species above, leading ultimately to upland species in zones above the floodplain.

The OHWL has also often been regarded as the mean high water line (or mark; Maloney and Aussness 1974). This would suggest that the major transition would correspond with the average annual flow peak, or the Q_2, the discharge with a recurrence interval of 2 years. Peak flows are plotted versus the return interval (a Weilbull plot) in Figure 55 and from that recurrence plot, the

Q_2 for the Bow River upstream of the Elbow River would be ~ 330 m^3/s. With the aerial photograph series we can assess this prediction and we did find that the river edge with a discharge of around 300 m^3/s does approximate the transition from the parafluvial zone to the zone with perennial vegetation (such as in Figure 55)

However, that location represents a somewhat unusual position, with a well-defined channel and extensive armouring along the river left bank, which would alter the river characteristics (Figure 56). That transition from the barren gravel bar to the dense riparian vegetation involves a slight step and it is very probably the combination of inundation pattern and shear stress, the erosive force corresponding with flow velocity, which normally defines the riparian transition (Benjankar et al. 2015). In zones with more complex surfaces, the transition is less abrupt, as displayed at the longer-term study site of the Point McKay Bar (Figure 57). In that location, some willows are inundated at discharges lower than the Q_2, as illustrated in Figure 57 (top), with a discharge of ~ 250 m3/s. That observation is confirmed by the study of Amlin and Rood (2001), with some positions with sandbar willow that inundated in most years and often for extended intervals (Figure 57, bottom). Thus, the OHWL provides a useful reference but with more complex, shallow riparian surfaces, the transition from barren zones to perennial vegetation is less abrupt than occurring as a sharp transition at the shoreline position corresponding to the Q_2 peak stage.

Following from these observations and especially the field assessments of the newly colonized riparian seedlings in 2015, we developed a sequence of elevational inundation zones, which are being colonized by different riparian vegetation types (Table 20). We can thus provide projections of the colonization patterns and these represent predictive maps of the anticipated future zones with riparian shrubland or woodland, or with flood-tolerant perennial plants such as sandbar willow or reed canarygrass, or finally for the lower elevation zones that would support annual colonization by ruderal annual plant species, but not perennial plants.

This strategy thus provided the basis for mapping the projected riparian vegetation types at the locations of concern along the Bow River through Calgary. These projections provide 'camo-maps', memorable naming that recognizes the resemblance to military camouflage.

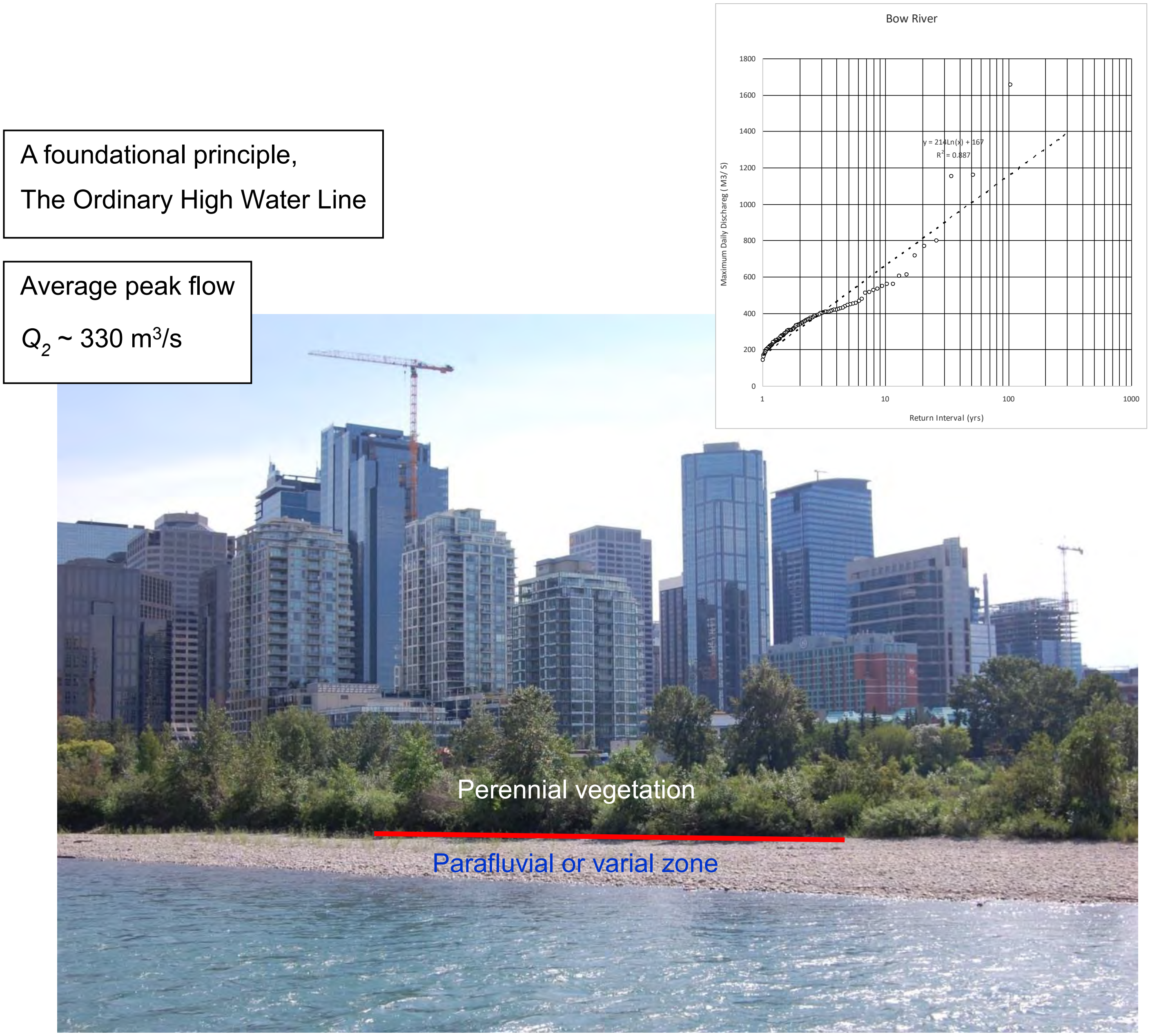


Figure 55. The study strategy involving the Ordinary High Water Line (OHWL, red line) that separates the band of perennial vegetation from the relatively barren parafluvial zone. The inset plot provides a peak flow recurrence analysis, with the maximum annual mean daily discharge versus the associated return (recurrence) interval.

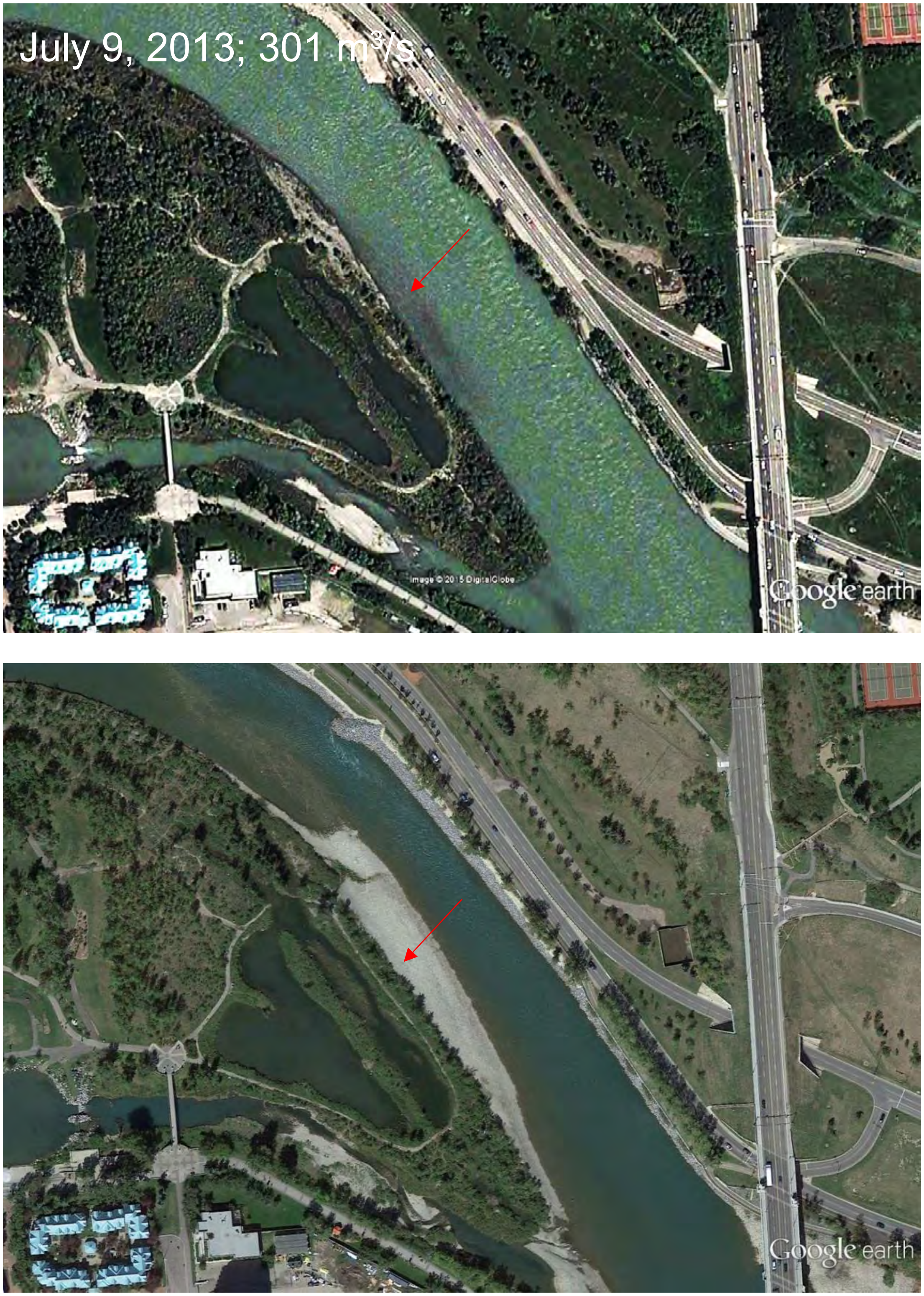


Figure 56. Aerial photographs of the zone displayed in the Figure 54 photograph, illustrating the transition from the barren gravel bar to the band of perennial riparian vegetation. The red arrows indicate the direction of the ground level photo. The upper photo displays the river inundation at around the Q_2, or average annual peak discharge, supporting the association between this and the Ordinary High Water Line (OHWL).

Figure 57. (Top) An aerial photograph of the Point McKay Bar, July 1, 2014, with a Bow River discharge of 254 m^3/s, somewhat below the Q_2 recurrence. Some zones with willows and especially sandbar willows were inundated at this flow.
(Bottom) Sandbar willows in the Point McKay Bar, May 28, 2001, inundated with a discharge of only 114 m^3/s. Some plants are cloaked with debris from recently higher flows. With a low-flow interval there was probably downward expansion of these willows.

Table 20. Bow River discharge thresholds for colonization by different riparian vegetation types on newly formed or scoured islands or gravel bars through Calgary.

Vegetation type	*Description*	*Approximate river discharge threshold*	*Aerial photograph date*
Woodland	Riparian woodland with trees (woody plants > 2 m tall) and primarily balsam poplars, along with various shrubs and understory plants.	350 m^3/s > Q_2, the peak that occurs in one-half of years	July 6, 2013 (other dates for some river locations)
Shrubland	Abundant shrubs (woody plants 0.5 to 2 m tall), commonly including various willow (*Salix*) species and river birch and other shrubs, along with herbaceous plants.	300 m^3/s	July 9, 2013 (various other dates for this and lower discharges)
Perennials	Relatively complete cover of perennial plants, with small shrubs (generally < 0.5 m) such as sandbar willows (*Salix exigua*), along with perennial herbaceous plants such as reed canarygrass.	250 m^3/s	July 1, 2014
Annuals	This zone would primarily support ruderal annual plant species, but some perennials may occur, generally with suppressed growth due to periodic inundation. Sweetclover may be especially common.	200 m^3/s	June 5, 2015
Transition	This zone may support scattered plants and primarily ruderal annuals such as sweetclovers. However, in flow-protected locations such as backwaters, there may also be some perennial plants and even inundation-suppressed sandbar willows.	150 m^3/s	June 8, 2015
Barren	This zone is generally barren of vegetation, except in flow-protected locations.	100 m^3/s	July 8, 2015

Shrub Island

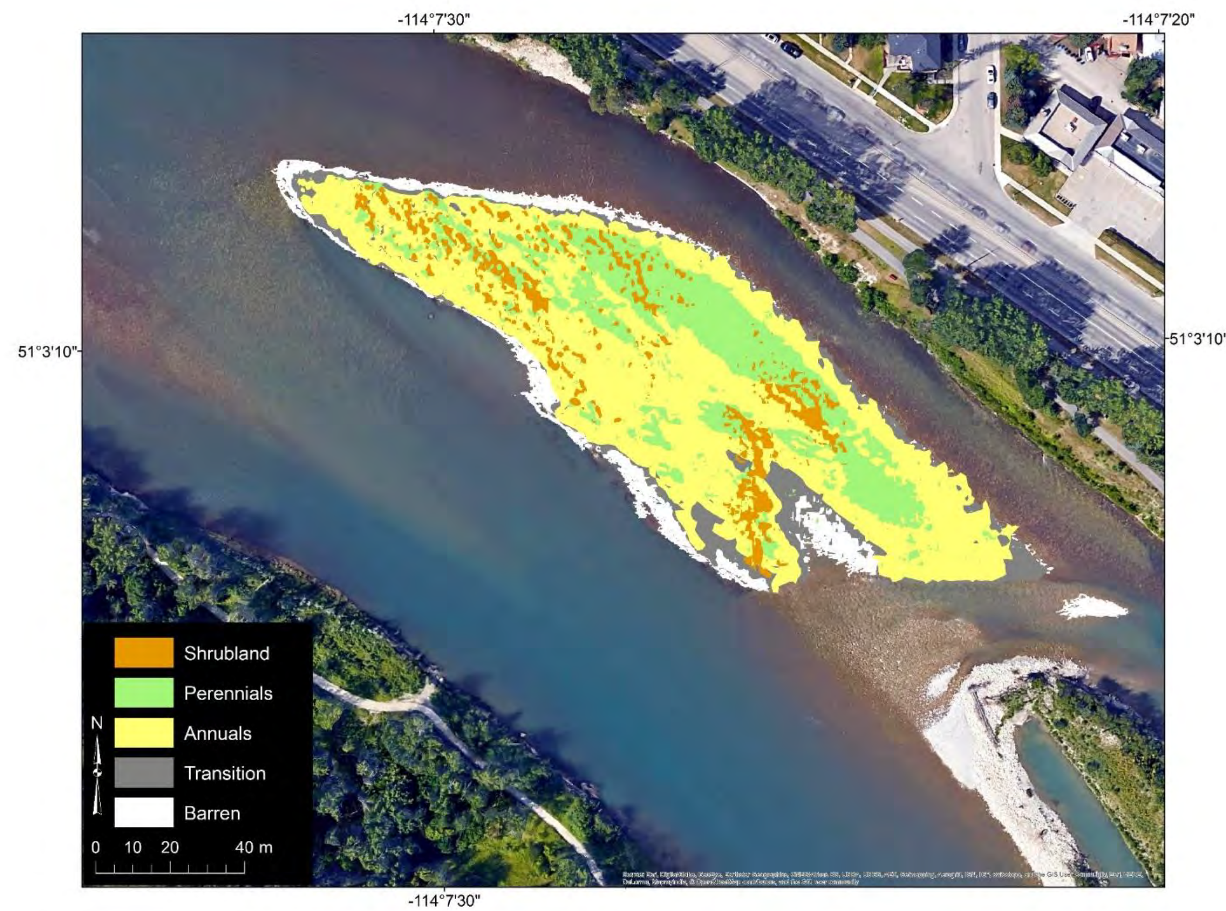


Figure 58. 'Camo-map' showing projected riparian vegetation types on the Shrub Island.

Figure 59. Post-flood aerial photographs of Shrub Island and Wooded Island displaying the inundations at different river discharges that were used to project vegetation colonization patterns.

Wooded Island

Figure 60. 'Camo-map' showing projected riparian vegetation types on the Wooded Island.

Crowchild Island Bar

Our projection for the Crowchild Island Bar is the most complex of the camo-maps and this reflects the extent and diversity of the surfaces of this large river feature. Prior to the 2013 flood, it consisted of a complex of shallow mid-channel islands (Figure 15). The flood produced extensive deposition of fairly coarse material which severed the river-right channel and converted the island complex to a massive gravel bar (Figure 15). This bar continues to display substantial complexity in surface topography and this is influencing the patterns of vegetation colonization (Figures 18 and 19). Some patches of willows survived the flood scour and these are expanding on the new bar surface. There are also other zones of colonization, with willows being abundant at the intermediate elevations, and balsam poplar seedlings that established commencing in the flood year 2013, and more extensive poplar colonization that has followed.

Following from these observed colonization patterns and from the relative elevations and inundation thresholds (Table 20, Figure 58) we thus provide the camo-map projection of Figure 59.With this woodland and shrubland development, we expect that this large bar will be somewhat stabilized and the consequence of the reduced flow along the river-right channel and the elevation and extension of the vegetated bar would likely be some flow restriction and redirection along the river-left channel and subsequently along the left bank. A bike-path and roadway onto Memorial Drive exist above the river-left bank and may be vulnerable to bank erosion. There is extensive bank-armoring along the left bank upstream and there might be some response to the extension, colonization and stabilization of the large Crowchild Island Bar. This might involve excavation or other modification of the bar and/or further armoring of the left bank.

Figure 61. Post-flood aerial photographs of Crowchild Island Bar displaying the inundations at different river discharges that were used to project vegetation colonization patterns.

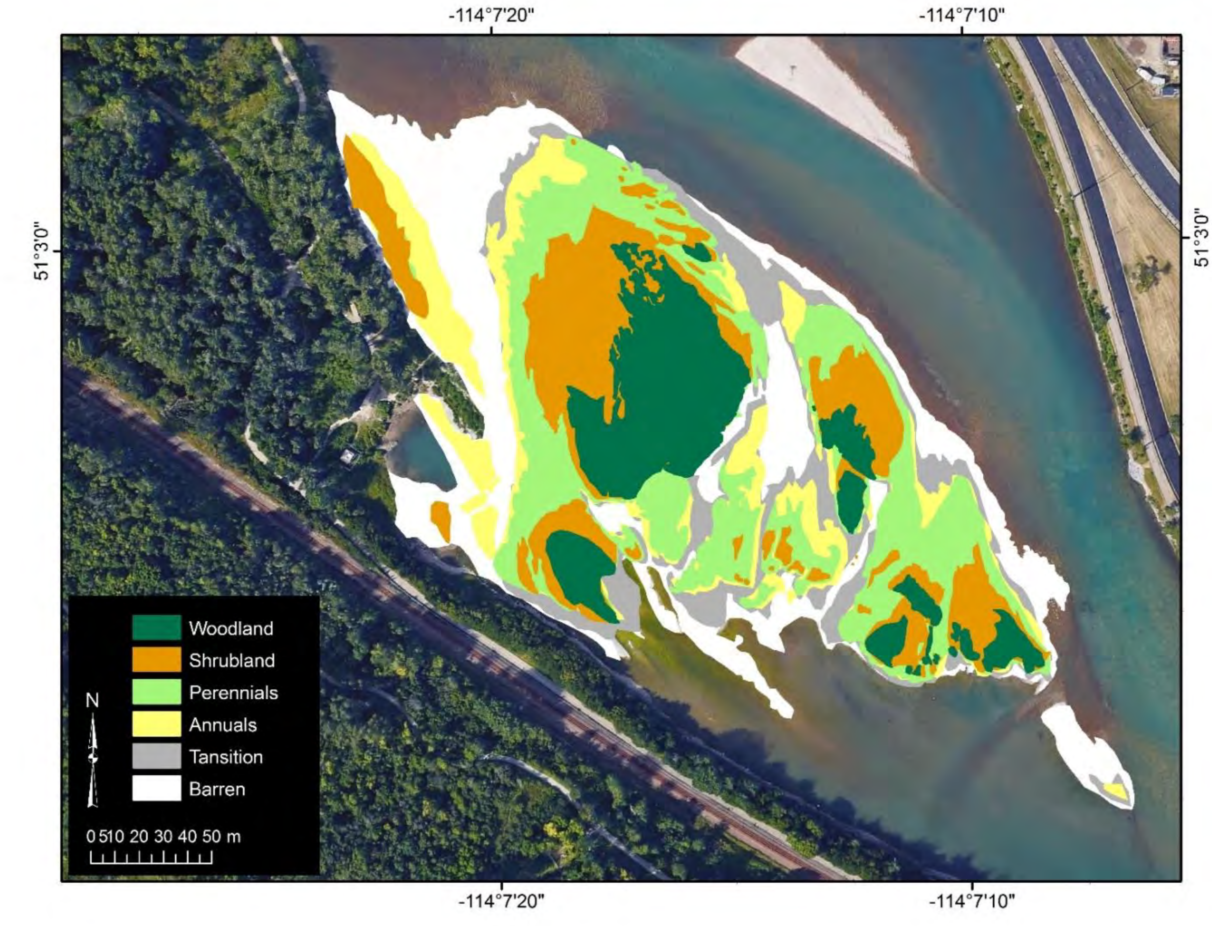


Figure 62. 'Camo-map' showing projected riparian vegetation types on the Crowchild Island Bar.

Tenth St. Island

The 10th St. Island was particularly identified as a location of concern, as we described in our prior consideration of the island development and vegetation colonization. Following from those observations we applied the inundation thresholds of Table 20 and considered the historic inundation patterns (Figure 60). Our subsequent projection indicates that there will be substantial woodland and shrubland development on this elevated and expanded island (Figure 61). An elongated woodland patch existed upstream of the bridge pillar at the left (north) edge of the island prior to 2013 flood (Figure 21). That patch persisted through the 2013 flood although it was thinned and an extension downstream of the pillar was substantially scoured (Figure 22). This island was substantially elevated and expanded by the flood and we observed substantial colonization by poplar seedlings, and by some other riparian plants (Tables 7 and 8). This new colonization supports the projection based on elevations and inundation and we thus strongly predict substantial expansion of perennial cover, which would also stabilize the island.

We anticipate at least two woodland patches, with one extending from the pre-flood patch and another small poplar grove adjacent to the LRT bridge (Figure 61). We also expect some woodland development on the river-right edge of the island downstream from another bridge pillar. Based on the elevations and inundation, there would subsequently be a large U-shaped patch of perennial vegetation, which would likely include extensive shrubs. We had also undertaken a map projection with slightly different inundation thresholds and this would also anticipate a U-shaped patch of perennial vegetation but, based on elevations alone, projected only annuals colonizing the mid-island zone within the 'U' (Figure 62). We observed the island in July, August and September and we have observed some poplar seedlings within this central zone. We consequently favor the projection in Figure 61 and anticipate that flow-exposure as well as elevation and inundation will be important. While the island zone within the U is inundated by moderate flows, as the woodland and shrubland of the U advance, this vegetation will block the flow, creating slack-water conditions within the U and avoiding the sheer stress that can limit riparian vegetation colonization and survival (Benjankar et al. 2014).

With the woodland zones along the island fringe, the whole lower portion of the island would be somewhat stabilized and there could be some further sediment trapping, which would also increase favorability for further vegetation colonization. Thus, while the camo-map provides a projection of the condition in one or two decades, it may be likely that with a longer interval the whole island would be colonized by woodland and would subsequently somewhat resemble the Elbow Park Island at the Mission of 4th St. Bridge over the Elbow River (Figure 39). There are five arched spans below the 10th St. Bridge and woodland colonization of the island could substantially impede flow conveyance through two of these. As is likely the case with the Mission Bridge, this could subsequently elevate river stages and increase the prospect for overbank flooding.

The vegetation colonization, maturation and succession are gradual processes, with time intervals of years and decades. There is subsequently limited urgency and it could be suitable to follow the vegetation development over a few more years before committing to actions such as partial excavation of the island. Conversely, it may easier and even productive relative to the gravel asset to undertake excavation while vegetation is limited.

Figure 63. Post-flood aerial photographs of the 10th St. Island displaying the inundations at different river discharges that were used to project vegetation colonization patterns.

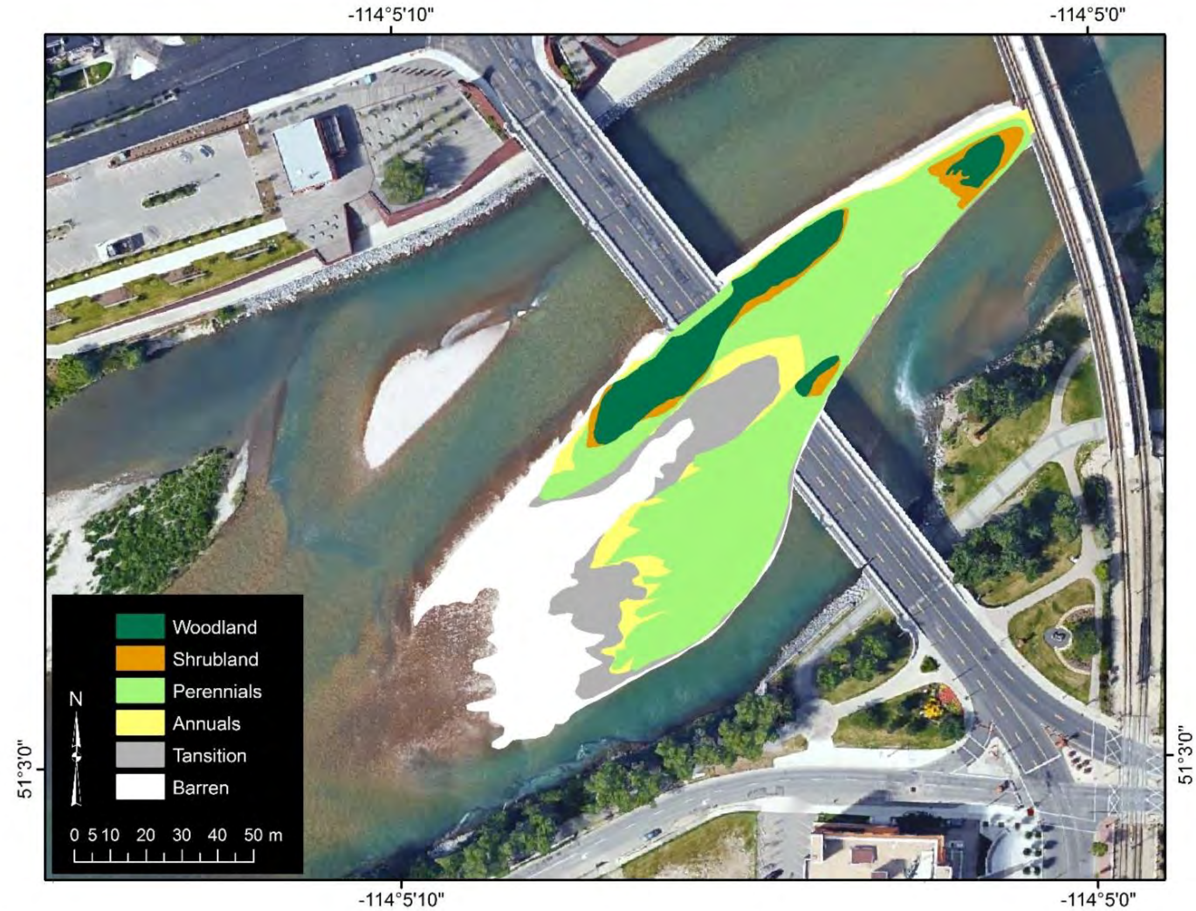


Figure 64. 'Camo-map' showing projected riparian vegetation types on the 10th St. Island.

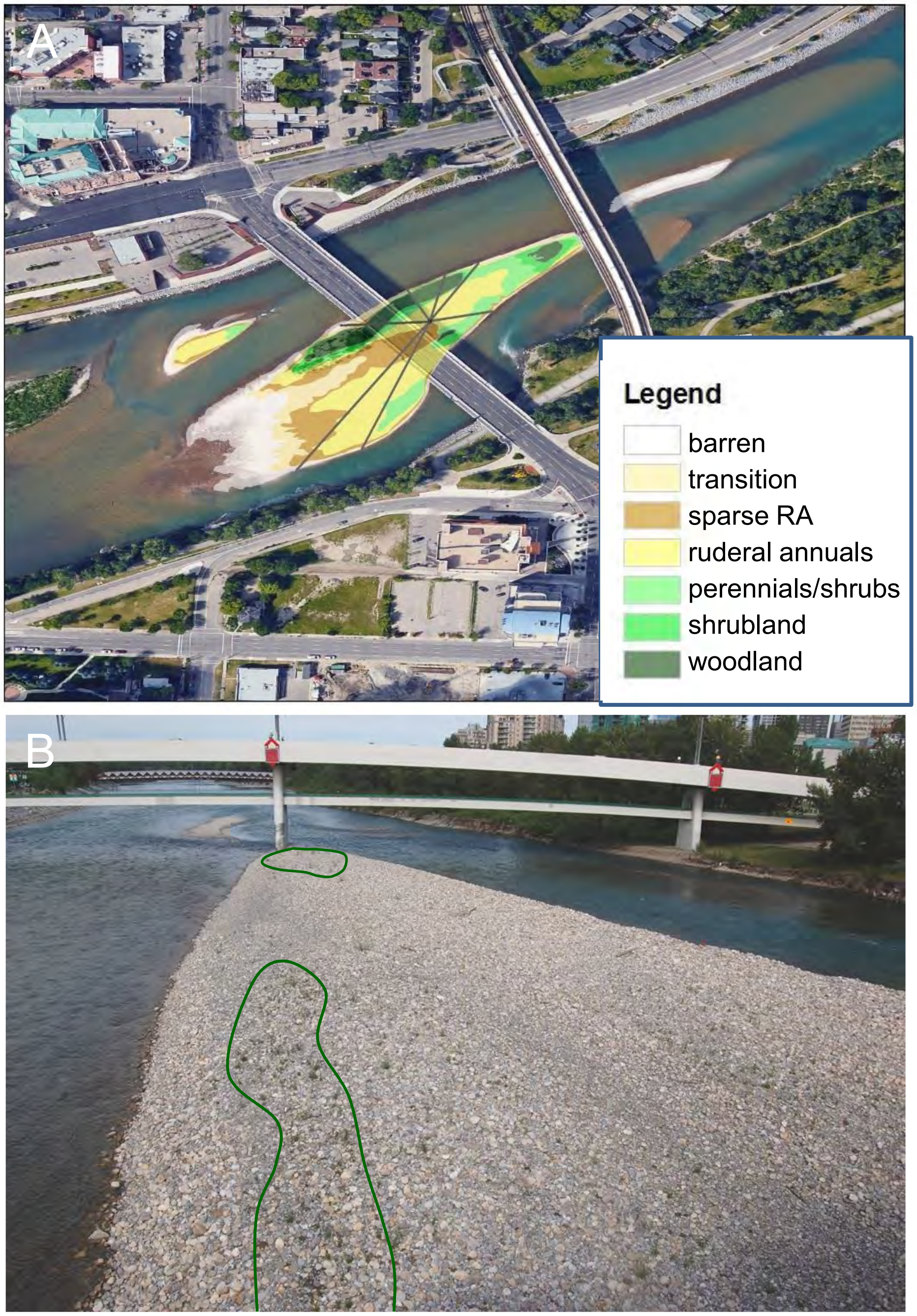


Figure 65. (A) An alternate 'camo-map, from that of Figure 61, showing projected riparian vegetation types when 10th St. Bridge is visible. (B) Poplar seedlings are established in the woodland patch.

Centre St. Bar

The Centre St. Bar was identified as a prospective problem site as this bar was elevated and expanded by the 2013 flood (Figure 27). Our sampling emphasis was closer to the Centre St. Bridge (Figure 28) since conveyance through the arched spans was of primary interest. We observed extensive colonization by balsam poplar seedlings and by other woody and herbaceous perennials and based on the inundation patterns (Figure 63) we anticipate that this elevated bar will develop into a substantial woodland grove (Figure 64). There would also be extensions of shrubs and other perennial plants around the woodland core. Based on the elevations, we anticipate that this new woodland patch would be downstream from the bridge but river conveyance through the bridge might be impeded by vegetation. However, we also observed substantial deposition of finer sediments in the upstream end of the bar, near the bridge and this might favor subsequent vegetation colonization, especially in low-flow years. It is important to recognize the interannual variations in river flow regime and aspects such as the Pacific Decadal Oscillation may produce multiple year high or low flow sequences and this would correspondingly raise or lower the vegetation distributions (as in Figure 57, bottom).

The anticipated development of the woodland patch across much of the lower portion of the bar would constrict the channel width and may thus be of concern even without impeding flow through the bridge spans. This would thus deserve further consideration and possibly hydraulic modeling of this river channel position with different levels of woodland development.

Figure 66. Post-flood aerial photographs of Centre St. Bar, displaying the inundations at different river discharges that were used to project vegetation colonization patterns.

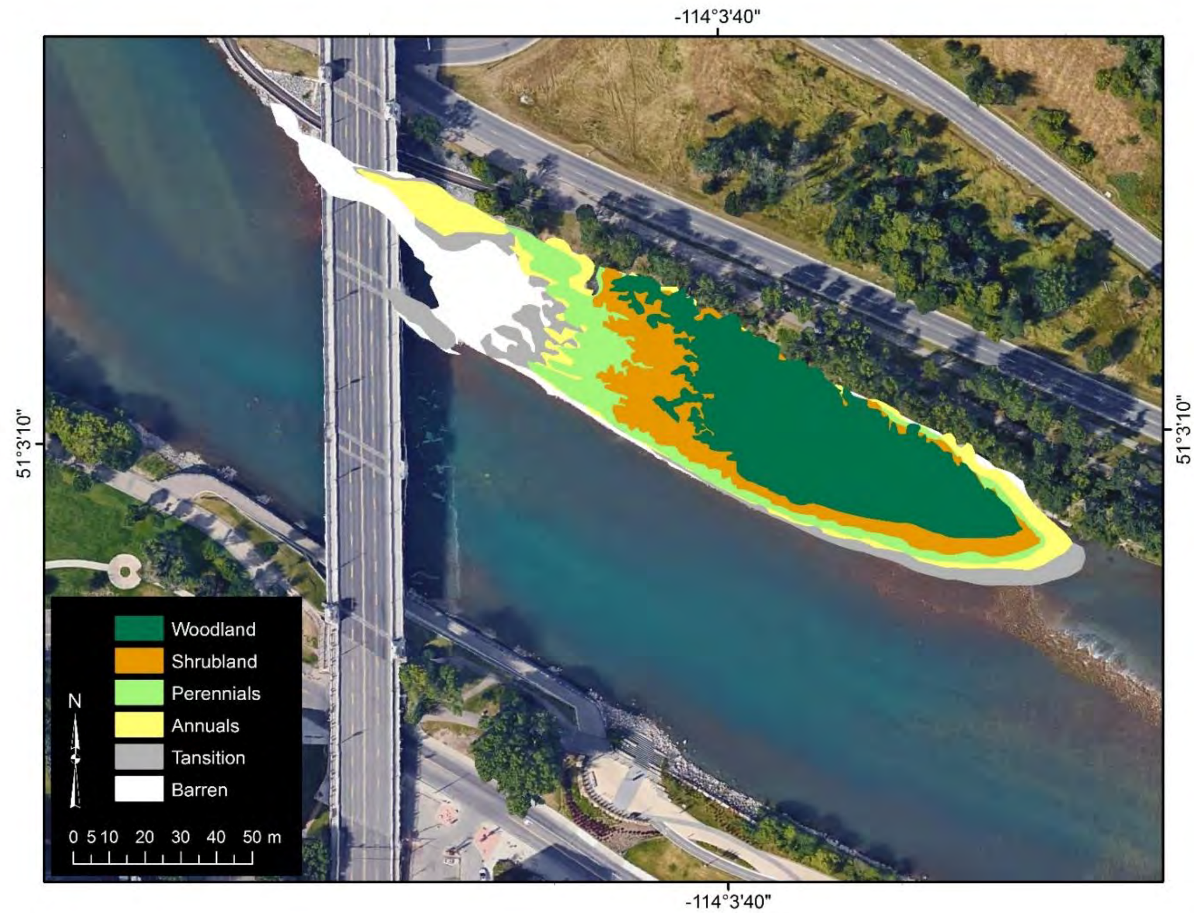


Figure 67. 'Camo-map' showing projected riparian vegetation types on the Centre St. Bar.

Glenmore Trail Bar

Figure 68. ‘Camo-map’ showing projected riparian vegetation types on the Shrub Island.

Figure 69. Post-flood aerial photographs of Glenmore Trail Bar, displaying the inundations at different river discharges that were used to project vegetation colonization patterns.

Carburn Park Island

The Carburn Park Island provided another position of major interest, but with somewhat different considerations than those at the three upstream sites that were modeled. The Carburn Park Island is an unusual site that follows from the artificial excavations that provided the prior pools that were captured by the 2013 flood. An elongated woodland patch persists from prior to the 2013 food and this feature involves a substantial elevational step above the other surfaces of the island; we anticipate that the woodland ridge will persist (Figure 66). As we presented, the lower, and more commonly inundated surfaces (Figure 65) are being densely colonized by reed canarygrass and other weeds (Figure 34) and this provides a zone that would provide weed propagules that would drift downstream. Following our field observations and as we discussed in the prior section, we anticipate that this may develop into a dense and extensive patch of reed canarygrass (Figure 66) and this outcome may be disfavored.

Figure 70. 'Camo-map' showing projected riparian vegetation types on the Carburn Park Island.

Figure 71. Post-flood aerial photographs of Carburn Park Island displaying inundations at different rivers discharges that were used to project vegetation colonization patterns.

Hull's Wood Bar

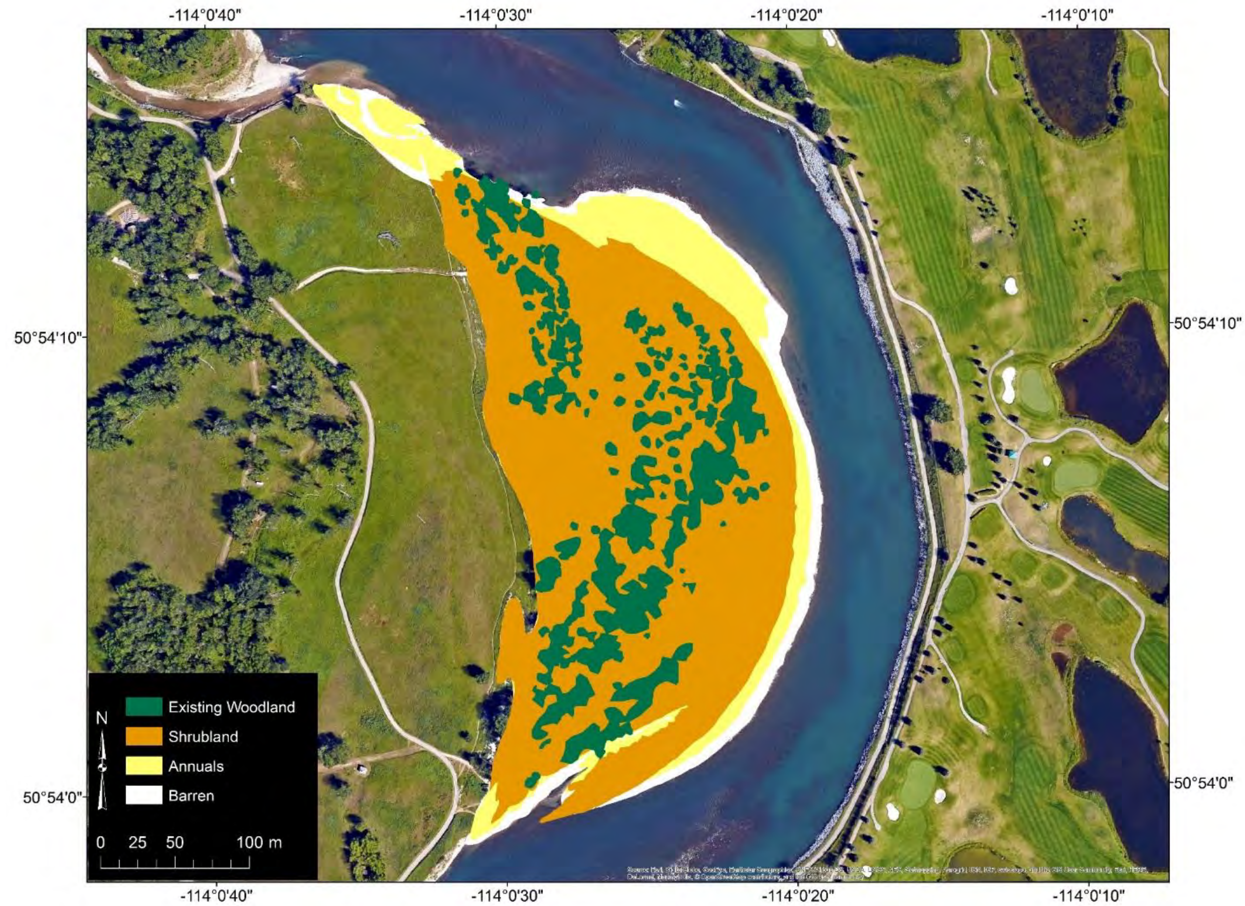


Figure 72.'Camo-map' showing projected riparian vegetation types on the Hull's Wood Bar. (Existing woodland was mapped using the 2014 Google Earth image.)

Figure 73. Post-flood aerial photographs of Hull's Wood Bar displaying inundations at different rivers discharges that were used to project vegetation colonization patterns. Google Earth aerial photographs were limited for this location.

Conclusion

We undertook a sequence of overlapping analyses of some of the newly formed or expanded gravel bars and islands along the Bow River through Calgary. Our study investigated the elevational occurrences of new vegetation and especially seedlings of balsam poplars and other native and introduced plant species. We coordinated these positions with elevations above the adjacent river surfaces and with the inundation patterns that reflect the changes in river discharge. This benefitted from the extensive collection of aerial photographs that have been taken of this river system, especially after the exceptional flood of June, 2013.

Following from these studies, we developed a method to project the distributions of different riparian vegetation types on the new surfaces. This provides some insight into the extent of the major pulse of riparian rejuvenation that was enabled by the 2013 flood. It also provides guidance relative to some particular locations where riparian woodland development could impede river flows and thus increase the risk of bank erosion or of overbank flooding with future flood events. These map projections may be useful in considering possible areas for additional bank armoring or for excavation of the gravel bars or islands to limit the development of riparian woodlands or shrublands, as a strategy to reduce impacts from future floods.

This Report emphasizes potential problem locations relative to elevations of risk to banks, infrastructure and overbank flooding due to colonization and development of riparian shrublands or woodlands. Alternatively, the analyses should be equally applicable for a complementary application. In locations such as along substantial downriver segments through Calgary and downstream especially to the Highwood River inflow, the 2013 flood finally provided substantial hydrogeomorphic disturbance which is essential for the rejuvenation of riparian woodlands. The methods and findings of this study should thus provide direction relative to prospective riparian recruitment zones that would particularly support the favored poplars and willows that contribute substantially to a number of valued ecosystem services. These findings and methods can thus assist in determining where riparian woodlands should be avoided and also where there is sufficient ‘room for the river’ to tolerate and encourage riparian woodlands which are critical for the long-term health of fishery and aquatic ecosystem and provide the richest wildlife habitats in Alberta and many other regions worldwide.

The study was novel in utilizing the extensive sequence of post-flood aerial photographs to determine inundation patterns for the various bars and islands. We had anticipated elevational surveys and hydraulic modeling but the displays of the actual inundation patterns at various flows are even more reliable. We anticipate that this approach may be applicable following major floods through other cities as this would likely prompt aerial photographs that have various applications such as for assessing flood patterns and infrastructure damage. We recommend that aerial photographs be taken a various flows and particularly at high flows, including at different intervals during the flood event.

The findings relative to different riparian plant species were largely expected and we thus anticipate a major woodland recruitment event along the Bow River after the major 2013 flood due to the proliferation of balsam poplars (*Populus balsamifera*) through seedling recruitment, combined with clonal suckering. The tolerance or resilience of willows was even greater than anticipated and we regard sandbar willow (*Salix exigua*) as the ideotype, or ideal form, for a flood-adapted woody plant. With a shoot form with many small diameter and pliable stems, the willow is bent over by flood flows, rather than resisting the flow and subsequently being broken or uprooted. The narrow leaves similarly provide limited resistance and this contrast to broader leaves that were stripped by the swift flood flows. Its shoot architecture thus probably explains its unique adaptation to the lowest elevation positions along rivers throughout North America.

Finally, we were surprised by the limited differentiation in elevational distributions of the different riparian plants. This contrasted somewhat with our observations along some rivers in warmer and drier regions such as along the Oldman River around Lethbridge, Alberta. We did observe some elevational banding and this might have reflected the phenology of seed release rather than seedling survival. Calgary is situated near the transition from the drier prairie to the aspen parkland, when local precipitation becomes sufficient to support aspens, another type of poplar tree. Additionally, due to river damming and flow regulation, flows of the Bow River are augmented (increased) through the warm and dry interval of mid- to late summer and this would elevate the alluvial groundwater, both the water table and the capillary fringe above. This would increase available substrate moisture for the riparian plants and diminish drought stress and associated seedling mortality. Thus, the combination of local climate and weather and flow regulation may favor seedling survival and reduce the elevation banding of different riparian plant species.

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