ALBERTA INNOVATES

CLEAN TECHNOLOGY: FINAL REPORT

The final report will use the following format to capture key results and outcomes developed during the reporting period. This represents the minimum information expected and additional topics relevant to the reporting period should be included. Your organization's template and formatting may be used instead of the Alberta Innovates, if preferred.

Project Title: **Expanding Functional Flows: Floods, Floodplains and Groundwater**
Project Start Date: May 1, 2016
Project End Date: October 31, 2019
TRL at Project Start: 5 Demonstration
TRL at Project End: 7 Successful Implementations
Project Partners: Alberta Environment and Parks, Canadian Foundation for Innovation (CFI), Chinese Academy of Sciences, City of Calgary, Conoco Phillips Canada, Natural Sciences and Engineering Research Council (NSERC), University of Lethbridge
Total Project Cost: $886,000
Total Funding from Alberta Innovates: $330,000 provided + $30,000 to follow

CONTACT INFORMATION:

Name: Stewart Rood and Larry Flanagan	
Title: Professors	
Company: University of Lethbridge	
Department: Biological Sciences	
Address: 4401 University Drive West	
Phone: 403 329 2327	Fax: 403 329 2082
Email: rood@uleth.ca	

1. Executive Summary

In Alberta, as elsewhere across Canada and worldwide, rivers provide the primary water sources for human uses, including agricultural irrigation, and municipal and industrial demands. River flows are also essential for the natural environment and sufficient instream flows are required to sustain the aquatic and riparian (streamside) ecosystems. Riparian woodlands provide Alberta's richest wildlife habitats and the cottonwoods, the dominant riparian trees, also stabilize the river banks, contribute to the aquatic food web and intercept contaminants, thus maintaining water quality for fish and for human uses.

The rivers of southern Alberta provide the headwaters for the South Saskatchewan River Basin (SSRB), and flow to Saskatchewan, Manitoba and ultimately, Hudson Bay. The rivers of the Oldman and Bow River sub-basins flow through the dry prairie regions and provide the focus for irrigation development in Canada. However, following excessive water withdrawal, the riparian woodlands have collapsed along some rivers within the SSRB. This decline was a focus during the controversial Oldman River Dam Project, and we worked with Alberta Environment to develop 'functional flows', deliberate patterns of dam operation to conserve and even restore the riparian and aquatic ecosystems.

The functional flow strategy emphasizes ecosystem rejuvenation during high flow years, when there is abundant water for irrigation and other uses, in order to increase the resilience for the inevitable, dry, low flow years. In this Alberta Innovates project we worked to: (1) assess the consequences of functional flows that had previously been implemented, and (2) expand the implementation for other rivers within the SSRB. We also (3) assessed the roles and influences of floods, especially following the exceptional and costly 2013 floods through Calgary and elsewhere in the SSRB. Finally, we (4) characterized the water uses and sources for riparian woodlands, which will assist with river basin water budgeting and functional flow prescriptions.

With a 'good news story', we determined that (1) the functional flow regime has succeeded in restoring riparian woodlands along the Oldman and Waterton Rivers, but the St. Mary River had passed an irreversible threshold since there are few surviving trees. Functional flows were (2) successfully implemented with the recent Twin Valley Dam Project along the Little Bow River, and woodlands along the Red Deer are still thriving after river damming. We found that (3) the 2013 flood enabled extensive riparian rejuvenation along the Bow River but woodland development would be unfavorable at positions such as through bridges, since this would impede future flood flows.

We determined that (4) through the summer, riparian woodlands use about 5 mm of water per day and for river basin budgeting, this value is multiplied by the woodland area. The water is provided through a combination of alluvial groundwater that infiltrates from the adjacent river, flood overflows and precipitation. Source tracking with H_2O isotopes increases our understanding of river valley ecohydrology and will contribute to informed dam operations and adaptive river valley management to sustain our valued riparian and aquatic ecosystems.

2. Table of Contents

(Right) The 'Bridge Grove' of riparian cottonwoods along the Oldman River in Lethbridge. The health and reproduction of this woodland was restored after the implementation of functional flows following the Oldman River Dam Project.
(Sept 2018, Stewart Rood)

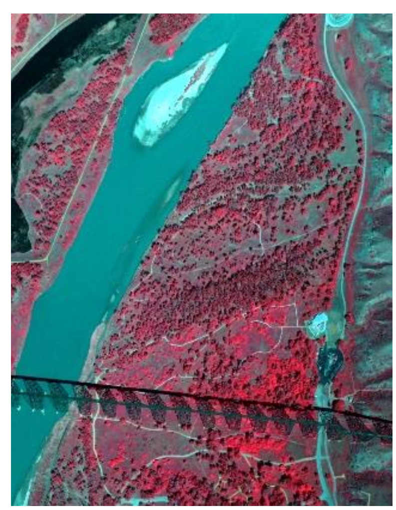
3. Introduction and Objectives

River dams provide the primary means of managing freshwater resources in Alberta, as in most regions worldwide. Most rivers in the South Saskatchewan River Basin (SSRB) are dammed, primarily to support agricultural irrigation, hydroelectric power generation, and municipal and industrial water uses. As a consequence of damming and water withdrawal, by 2000 the Province of Alberta had recognized that some river reaches had been over-allocated and this resulted in declines of the aquatic (instream) and riparian (streamside) ecosystems. This challenged the *Water for Life* objective of *Healthy Aquatic Ecosystems* and prompted closures of the Oldman, Bow and South Saskatchewan Rivers for further water withdrawals. Subsequently, water resource managers have sought to develop river management strategies to better sustain Alberta's river ecosystems.

We have worked extensively with Alberta Environment and Parks (AEP) to develop and implement river regimes that enable environmental conservation, while still enabling water management for the economic objectives. Our major strategy involves Functional Flows, which provide regulated instream flow patterns in high-flow years that seek to fortify the river ecosystems and thus provide resilience for the inevitable low-flow years. Progress on the functional flow strategy has advanced readily, and the major floods in 2013 introduced another consideration, providing both challenges and opportunities for comprehensive river resource management.

In this AB Innovates project, we continued to advance our understanding of river flow regimes in the SSRB, and how dam operations and functional flow regimes could benefit environmental health while also supporting human uses and economic prosperity. We investigated water exchange between rivers and floodplain groundwater, and water use by the floodplain forests along the Oldman and Red Deer Rivers. This relates to the largest knowledge gap for river basin water balance models that are essential to optimize river regulation in the SSRB. We quantified the amount of river water used in evapo-transpiration (ET) by riparian cottonwood ecosystems and determined the water sources for riparian woodlands how this ET flux is regulated by environmental conditions and influenced by the regulation of river flow patterns.

We extended our studies from the Oldman Basin northward to the Bow River and the Red Deer River, which is the SSRB tributary that remains open for further water allocation. We undertook overlapping research activities along the different rivers with common themes of river regulation and floodplain ecohydrology and worked to extend the implementation of functional flows in the SSRB.



(Right) False color infra-red photograph of the Oldman River floodplain study site. The red color indicates substantial water use by the riparian cottonwoods.

Within this Alberta Innovates project our *objectives* were to undertake research and implementation relative to overlapping themes, and we made considerable progress in all four:

(1) Functional Flow Assessments: We assessed the responses to the prior implementation of functional flow regimes for the Oldman River and especially its dammed southern tributaries, the Waterton and St. Mary Rivers;

(2) Functional Flow Implementations: We modelled and refined the implementation of the functional flow strategy for the Little Bow and Red Deer Rivers in collaboration with resource managers from Alberta Environment and Parks; and

(3) Floods and (River) Hydrology: We assessed the riparian responses to the major 2013 floods especially in the Bow River basin and refined the functional flow strategy to consider floods and flood flow attenuation.

(4) Water Use and Sources: We assessed the water use and sources by floodplain forests using eddy covariance flux tower derived evapo-transpiration measurements, stable isotope analyses, and ground-water table variations;

This project addressed research needs associated with the *Water for Life* priority of *Healthy Aquatic Ecosystems*, and also relates to balancing environmental and economic demands, relating to *Reliable Water Supplies for a Sustainable Economy*. These aspects were endorsed in *Alberta's Water Research and Innovation Strategy* (AWRIS, 2014) and in the Government of Alberta Water Conversation, it relates to *Water Management*.

Technology Readiness Level (TRL)

Our contributions to the prescription and implementation of environmental flow regimes have extended from scientific verification to real-world implementation. We were actively involved in the development of the operations plan for the Oldman River Dam and this involved flow ramping in high flow years, in accordance with our 'Recruitment Box Model'. That operational strategy was subsequently implemented for the other large dams in the Oldman River Basin, the St. Mary and Waterton Dams. That approach to assess and refine dam operations strategy was subsequently implemented for the two subsequent river dams: the Pine Coulee Project on Willow Creek and the Highwood Little Bow Project, which included the new Twin Valley Dam on the Little Bow River.

As these projects have now been completed and the flow regimes implemented, we have learned that: (1) the flow projections were accurate, and (2) the environmental outcomes relative to channel processes and the floodplain ecosystems have been consistent with the projections in the environmental impact assessments. It has been suggested that restoration is proof of ecological understanding and the successful outcomes demonstrate a solid scientific foundation.

Internationally, this functional flow strategy is sometimes referred to as the 'Oldman Model'. It has been successfully applied to other rivers of western North America, including the Bill Williams R., AZ; the Kootenai R., MT and ID; the Snake R, ID; the Bridge and Duncan Rivers, BC; and it enabled a dramatic success along the Truckee R. in NV. During the Alberta Innovates project we extended our collaborations with international scientists and resource managers.

Each successive implementation has provided further insight into the application and all have provided measureable success relative to river health. A key component of the adoptions is that they required only slight reduction or sacrifice in the economic objective such as irrigation agriculture or municipal water supplies. There were modest revenue losses for the hydroelectric dams. We consider, 'win-win' as less likely and seek 'win-neutral' applications, with environmental and social benefit without substantial economic cost.

The northward advancement to the *Red Deer River* was one focus of this AB Innovates project, and the river basin modeling projects by *WaterSmart* and *HydroLogics*. We developed a software module to prescribe functional flows and a scenario simulation demonstrated the feasibility. We found that flow alterations were moderate after the Dickson Dam was constructed. The environmental impacts have been correspondingly moderate, although there is opportunity for refinement to dam operations.

Our findings could lead to further northward application such as for the *North Saskatchewan River* and *Peace River*. This would be directly relevant to another major dam, *'Site C'*, which is under construction on the Peace River in BC near the Alberta border. Many of the environmental impacts from that BC project would occur downstream within Alberta.

(Right) Healthy riparian woodlands along the Red Deer River through Dinosaur Provincial Park. With limited flow alteration from Dickson Dam, the cottonwood groves are thriving.
(June 2018, Laurens Philipsen)

3.1 Project Description

With the *Alberta Innovates* proposal we developed this table of *Tasks and Milestones*, with slight organizational revision during the project. Substantial progress was made on each task, often exceeding the research plan.

<table>
<tr><th>Task Number & Name</th><th>Task Description</th><th>Start Date</th><th>End Date</th><th>Status and Comments</th></tr>
<tr><td>Task LF1: Floodplain Forest Water Source and Water Use</td><td>Analyses of water isotopic composition, river, groundwater, precipitation, trees</td><td>May 2016</td><td>May 2019</td><td>Journal papers describe the water exchanges and woodland sources</td></tr>
<tr><td colspan="5">This task is complete. Based on initial analyses (T. Orchard’s MSc thesis research) for tracing plant water use using stable hydrogen isotope ($^2H/^1H$) measurements, we anticipated that alluvial groundwater that originated from the Oldman River was the primary cottonwood tree water source. With additional data and use of oxygen isotope ($^{18}O/^{16}O$) analyses, we found that local rainfall provided an important contribution to tree water use even in a drought year. This matches the bimodal vertical tree root distribution and will require some revisions to our projections of river water use. A journal paper has been published on-line (#17).</td></tr>
<tr><td>Task LF2: Floodplain Forest Water Source and Water Use</td><td>H_2O, CO_2 and methane from Oldman River Floodplain Forest</td><td>May 2016</td><td>Oct 2019</td><td>Reference flux tower maintained in Oldman River floodplain –theses, journal papers, presentations</td></tr>
<tr><td colspan="5">These studies follow-on from the prior AI-EES Functional Flows project. We have now published three journal papers (#8, #14, #20), including descriptions and modelling of seasonal water use in cottonwood forests and upscaling for the Oldman River valley. We have also compared water-use and water use efficiency between cottonwood forests and the adjacent native grassland on the plateau above the river valleys. The grassland ecosystems rely exclusively on precipitation inputs, while the cottonwood forests make use of a mixture of precipitation and alluvial groundwater. We’ve added methane as another compound to monitor and have installed a methane instrument on our flux towers and have also developed a system for direct measurement of methane emission from cottonwood stems. Early results indicate significant methane release from tree stems, which might be an important contribution to local greenhouse gas budgets.</td></tr>
<tr><td>Task LF3: Floodplain Forest Water Source and Water Use</td><td>Energy and ecosystem fluxes from multiple floodplain forests</td><td>May 2016</td><td>Oct 2019</td><td>Trailer-mounted flux tower positioned in various woodlands - MSc thesis in progress, conference presentations</td></tr>
<tr><td colspan="5">We deployed the mobile flux tower in a riparian woodland along the Red Deer River in the summers of 2016 and 2017. These flux and meteorological data, along with similar data collected on the Oldman River, are being used to help develop and validate model calculations of cottonwood ecosystem photosynthesis and water use using remote sensing of vegetation greenness based on Landsat and other satellite measurements. The remote sensing measurements and related model calculations will allow us to upscale estimates of cottonwood photosynthesis and water-use on extensive landscape scales.</td></tr>
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<tr><td>Task SR1: Floods and Floodplain Forests</td><td>Analyses of historic peak flows in SSRB</td><td>May 2016</td><td>Oct 2016</td><td>Presentations and journal paper</td></tr>
<tr><td colspan="5">Contrary to expectation based on the ‘climate intensification’ hypothesis, peak flows have significantly decreased along some rivers in the SSRB. We provide a likely mechanism due to changes in snow melt following winter and spring warming. These findings were provided at the national Canadian Water Resource Association meeting (P6) and prompted substantial interest. Journal paper #3 reports these findings.</td></tr>
<tr><td>Task SR2: Floods and Floodplain Forests</td><td>Assessments of environmental outcomes from functional flow implementations</td><td>May 2016</td><td>May 2018</td><td>Presentations and journal papers</td></tr>
<tr><td colspan="5">The field studies demonstrated environmental benefits from the implementation of functional flow regimes for the Waterton River and Little Bow River, while the St. Mary River suffered from nearly complete cottonwood mortality, eliminating the seed source for replenishment. Journal papers #2, #4, #5 and #10 describe these patterns.</td></tr>
<tr><td>Task SR3: Floods and Floodplain Forests:</td><td>Analyses of woodland colonization through Calgary</td><td>May 2016</td><td>Oct 2019</td><td>Completed Report to City of Calgary, presentations, reports and paper</td></tr>
<tr><td colspan="5">This provided the basis for the ‘Silver Lining Project’ that was also supported by Alberta Environment and Parks through the Watershed Resiliency and Restoration Program. We found prolific recruitment of balsam poplars and other riparian vegetation after the exceptional 2013 flood. Findings are provided in in Presentation 5, and Reports R1, R2, R5. The first journal paper has been published (#19), and another is in preparation.</td></tr>
<tr><td>Task RDR1: Red Deer R. - Functional Flows</td><td>Analyses of historic hydrology and flow regulation for the Red Deer and other regional rivers</td><td>May 2016</td><td>May 2017</td><td>MSc Thesis and journal paper</td></tr>
<tr><td colspan="5">Unlike Alberta’s southern rivers that drain the Rocky Mountains, the Red Deer River has displayed little change and flows of Alberta’s northern rivers are increasing. This demonstrates regional differentiation in the hydrologic consequences from climate, as reported in papers #7 and #12.</td></tr>
<tr><td>Task RDR2: Red Deer R. - Functional Flows</td><td>Channel patterns and riparian woodlands – air photos and field assessment</td><td>May 2017</td><td>Oct 2019</td><td>MSc Thesis and journal papers</td></tr>
<tr><td colspan="5">Following the Dickson Dam, riparian cottonwoods through Dinosaur Park remain in good health. These trees are dependent upon sufficient instream flows as analyzed in paper #13 and another manuscript is in preparation.</td></tr>
<tr><td>Task RDR3: Red Deer R. Functional Flows</td><td>Modeling and Implementation of Functional Flows</td><td>May 2016</td><td>May 2019</td><td>Incorporation of flow ramping in the Dickson Dam operating plan</td></tr>
<tr><td colspan="5">The Functional Flow routine and performance measure was developed and implemented for the OASIS SSRB model, with WaterSMART and HydroLogics.
The analyses of the Red Deer River riparian health and population status revealed that the prior operation of the Dickson Dam has enabled continuing woodland recruitment. Operational refinements should provide more gradual flow ramping and environmental benefit, with minimal cost or impact on other objectives. This analysis was included in an MSc Thesis and a journal paper is in preparation.</td></tr>
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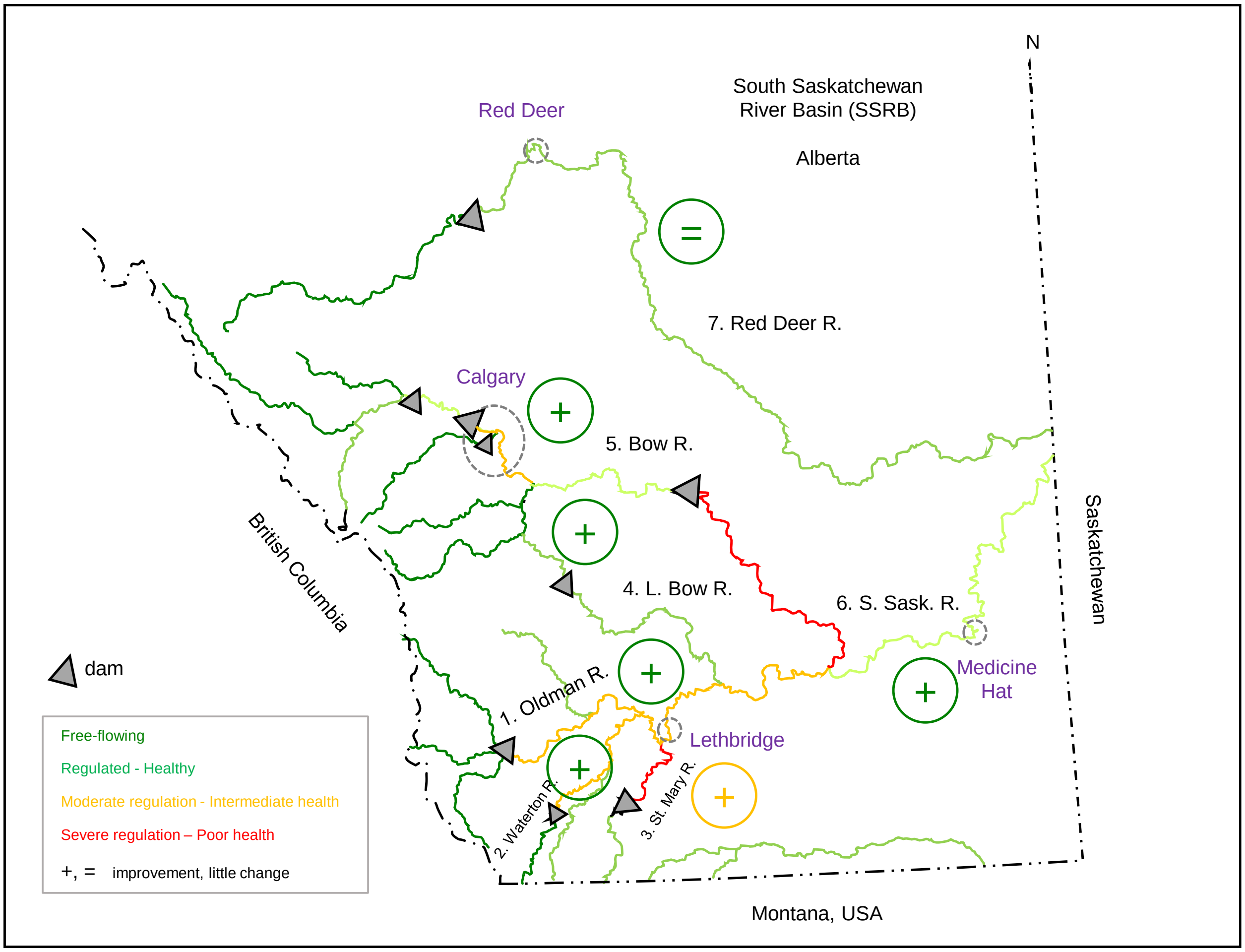
4. Project Results

A Graphical Summary Related to Functional Flows



Rivers and dams in southern Alberta, with colors representing conditions ~ year 2000. The circles indicate responses to recent flow regulation, with functional flow regimes for the southern rivers, and after floods for the Bow and Red Deer Rivers.

Functional flows represent a ‘good news story’. These provide a dam operation strategy to sustain healthy river ecosystems, without sacrificing the economic objectives of water management for irrigation, industrial and municipal needs, and hydropower.

The strategy was developed with the controversial Oldman River Dam Project and subsequently implemented for the other dammed rivers in southern Alberta. The studies in this Alberta Innovates project analyzed the river flow patterns and revealed environmental improvements with the functional flows, and after flood events.

4.1 Functional Flow Assessments

The Oldman River and its southern tributaries have provided a national focus for water resource management, with progressive damming and diversion through the twentieth century. Some rivers or reaches displayed environmental collapse by the 1980s, when the Oldman River Dam Project was approved, after a half-century of consideration.

With the Oldman River Dam Project, functional environmental flows were implemented for the Oldman River Dam and also for the two other major dams in the sub-basin, the Waterton Dam and St. Mary Dam. Minimal flows along all three rivers were substantially increased with the implementation of the Oldman Dam in 1993. Subsequently, deliberate flow ramping from the three dams began in 1995 after the highest flood flow of the century-long record. More deliberate regulation followed in 2011 after high flows in 2010. Progressive flow ramping was also implemented in 2014, a wet year with some flooding.

The Oldman River (#1 on p. 9 map) – Environment Benefit from a Controversial Dam

The Lethbridge Northern Irrigation District (LNID) weir was constructed across the Oldman River on the Piikani (Peigan) Nation lands around 1920. The headworks and diversion canal were progressively expanded and by the drought of the 1980s, only a meagre flow was passed downstream during mid- to late summer, when irrigation demands were high and mountain snow fields had melted. The insufficient instream flows led to decline in the riparian cottonwoods and lethal conditions for fish, due to excessive warming and oxygen depletion.

The Oldman River Dam allowed for trapping of the high spring flows and subsequent downstream release during the irrigation interval. This resulted in a dramatic increase in summer flows during dry years, and subsequently, an environmental benefit from the Oldman River Dam Project, relative to the pre-dam interval with insufficient instream flows through the summer. This recovery of summer flow has had dramatic benefit for the riverine ecosystems and restored health and reproduction of the cottonwood forests along the Oldman River, from the LNID weir downstream through Lethbridge to the junction with the Bow River and then downstream along the South Saskatchewan River (#6 on map).

The combined functional flow regime from the three dams in the Oldman Sub-Basin provides favorable flows downstream through Medicine Hat and to the Lake Deifenbaker Reservoir behind the Gardiner Dam, in Saskatchewan. Journal papers 6, 8, 20 analyze the restored riparian woodlands along the Oldman River, including analyses of water use with an eddy covariance flux tower, and water sources determined by analyses of stable isotopes of water.

The Waterton River (#2 on map) – Successful Restoration with Modest Flow Alteration

The Waterton Dam was completed around 1964 and water was diverted from the Waterton Reservoir to the Belly River and subsequently the St. Mary Reservoir, for distribution throughout the extensive irrigation districts eastward all the way to Medicine Hat. With the low flows through the 1980s drought, there was cottonwood die-back and limited woodland replenishment.

The functional flow regime was implemented from the late 1990s and there was clear evidence of woodland recovery. The established trees were restored and reproduction resumed. This provided a 'good news' story since there was no sacrifice in irrigation agriculture and a relatively modest increase in the summer flow provided ecosystem recovery. The response was greater than anticipated and with the flow ramping, there was also prolific seedling reproduction in high flow years. These environmental improvements were characterized in papers 5 and 10 and the MSc student involved, Stephen Foster, has been hired by Alberta Environment and Parks.

The St. Mary River (#3 on map) – Past the Point of No-Return

Originating primarily from snow melt in Glacier National Park, Montana, the St. Mary River has provided a focus for international water sharing. Frictions around 1900 contributed to the Boundary Waters Treaty and creation of the International Joint Commission.

The St. Mary River was the first Canadian river with substantial development for irrigation and through the twentieth century the extent of water withdrawals progressively increased. By the drought interval of the 1980s, river health was in poor condition and by the time that functional flows were implemented along with the Oldman River Dam Project, around 95% of the riparian cottonwoods had died.

Functional flows commenced in the late 1990s but there were almost no remaining trees to provide a seed source. Even though barren gravel bars were abundant and ideal flow and stage conditions were provided, there was very little cottonwood recruitment. A few cottonwood patches were established but these were harvested by beaver and deer, further stressing the woodland population. As a desperate action and to confirm the seed source limitation, we undertook a novel attempt, by sticking branches with nearly mature seeds into the ideal elevations for seedling recruitment. Seedlings followed, confirming our interpretations (as described in paper 4) but these progressively died due to drought and deer browsing. This could be undertaken with a larger scale but would be labor-intensive and subsequently, very costly.

While the cottonwood groves are very unlikely to recover, the functional flow regime led to substantial clonal expansion of the riverside sandbar willows (*Salix exigua*) and the lower St. Mary River is becoming recognized as an excellent trout stream. The introduced rainbow trout have become naturalized and reproducing, and while their densities are well below those along other rivers such as the Crowsnest, the St. Mary trout are commonly quite large.

4.2 Functional Flow Implementations

The Little Bow River Got Bigger (#4 on map) - Flow Augmentation Benefits the River Ecosystem

For most tributaries in the SSRB, water is withdrawn for irrigation and other uses. The opposite alteration, flow augmentation, has taken place for the Little Bow River. Diversion from the Highwood River into the Little Bow Canal and subsequently the Little Bow River commenced in the early 1900s and progressively increased through the twentieth century. By the 1980s, the diversion of water from Highwood River in the late summer was considered stressful for Bow River trout, which use the Highwood River for reproduction.

To address this problem and to increase the water supply along the Little Bow River downstream, the Highwood/Little Bow Project was undertaken. This involved two components: (1) expansion of the Highwood River Diversion and Little Bow Canal, to permit increased water withdrawal during the high spring flows, and (2) construction of the Twin Valley Dam and reservoir, to permit storage for subsequent release during the low flow interval of mid- to late summer.

We contributed to the development of the diversion and storage regimes which again included the functional flow strategy. As with the Oldman Sub-Basin, this involved increased minimum flows and flow ramping after the spring peak. We developed projections of the flow, channel and vegetation responses.

The new flow regime was implemented more gradually than anticipated, since there was less irrigation expansion than projected. With the higher flows along the Little Bow River, the channel was widened, as we predicted. However, the sequence was unexpected. We predicted that higher flows would lead to vegetation mortality that would release the banks, allowing erosion, In contrast, the plant mortality was limited and direct bank slumping occurred, with plugs of vegetation and bank materials shearing into the river.

As we predicted, with the increased flow regime there were increases in riparian shrubs and especially sandbar and Bebb's willows. With the increasing shrubs, birds increased and especially riparian specialist species. This sequence was described in paper 2.

That published study reported outcomes up to the spring of 2013. The June 2013 flood through High River was exceptional and this resulted in massive flood overflows into the Little Bow River. This destroyed many culverts and bridges but homes or other developments are sparse in the floodplain zone. Very encouragingly, after the 2013 flood, there are now new locations with balsam poplar seedlings saplings and we expect that over time there will be riparian woodlands that progressively extend downstream along the Little Bow River. This river valley was historically barren of trees or large shrubs and correspondingly, the First Nations name translates to 'Naked River'.

The Little Bow system demonstrates that water is the key environmental asset along a river. While water withdrawal depletes the riverine environment, the opposite alteration, flow augmentation, can benefit the environment. For both alterations, deliberate instream flow regulation is essential for ecosystem health and the functional flow strategy has now been successfully implemented for SSRB rivers with decreasing and increasing flows.

The Red Deer River (#7 on map) – Remaining Healthy Following the Dickson Dam

This river is a current focus of an Alberta Ingenuity (AI-EES, AI)/WaterSmart project to expand the OASIS SSRB hydrologic model. New modeling includes a riparian recruitment module that assesses flows for cottonwood colonization. The river is also the focus of our AI Functional Flows project, which seeks to prescribe instream flows for riparian and aquatic conservation.

Our proposed WRRP project will extend from the Functional Flow program and investigate the environmental opportunities that follow from major flood events. There will be analyses of the flood history and particularly the flow patterns in the flood year 2005 and in subsequent years, and the environmental consequence relative to riparian cottonwoods (balsam poplars, prairie cottonwoods and hybrids). There will also be analyses of the recent years, 2013 and 2014.

4.3 Floods and River Hydrology

The Bow River (#5 on map) – Rejuvenation of Aging Woodlands with a Major Flood

Ten dams have been constructed on the Bow River system upstream from Calgary. These were primarily for hydroelectric power generation and there was limited consideration for environmental flows. The combined reservoirs moderate flows and minor floods are attenuated. Unlike the Oldman River system, summer flows are sustained through Calgary since the major irrigation diversions occur downstream at the Carseland Weir and Bassano Dam.

After floods in 1929 and 1932, an unusual eight-decade interval followed without a major flood along the Bow River. The flow attenuation and lack of major floods has resulted in the river channel being simplified and static, and consequently the balsam poplar groves lack juveniles that are essential for population replenishment.

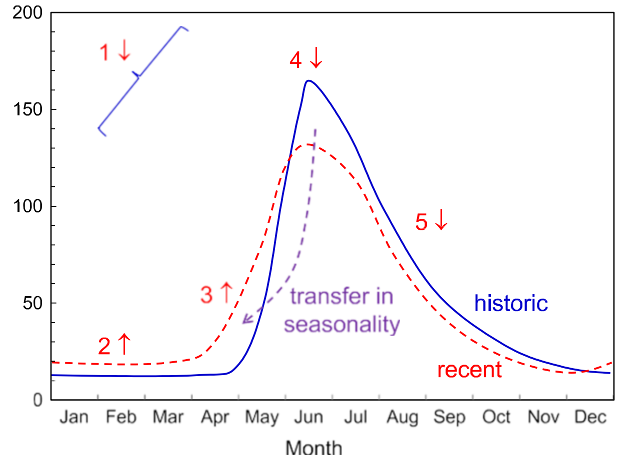
The 2013 flood provided a unique opportunity since it produced extensive sediment scour and deposition, producing abundant new gravel bars and floodplain deposits. These were barren of vegetation in 2013 and available for seedling colonization. This was prolific and primarily the balsam poplar, the native riparian poplar in this region, which is very closely related to the black cottonwood of British Columbia.

The new woodlands will provide rich environmental assets for many locations along the Bow River. However, there are also 'hazard' locations such as through bridges, where riparian woodlands are disfavored, since the trees and shrubs would impede future flood flows (right). We developed an efficient method to analyze and project vegetation colonization for 'opportunity' and 'hazard' locations (paper #19).

At bridge locations, the development of riparian woodlands would impede future flood flows. We identified three major hazard locations, including the Centre St. Bridge (right). There was prolific seedling colonization of this expanded gravel bar, which will be excavated (scraped) to prevent woodland development (Report 5).

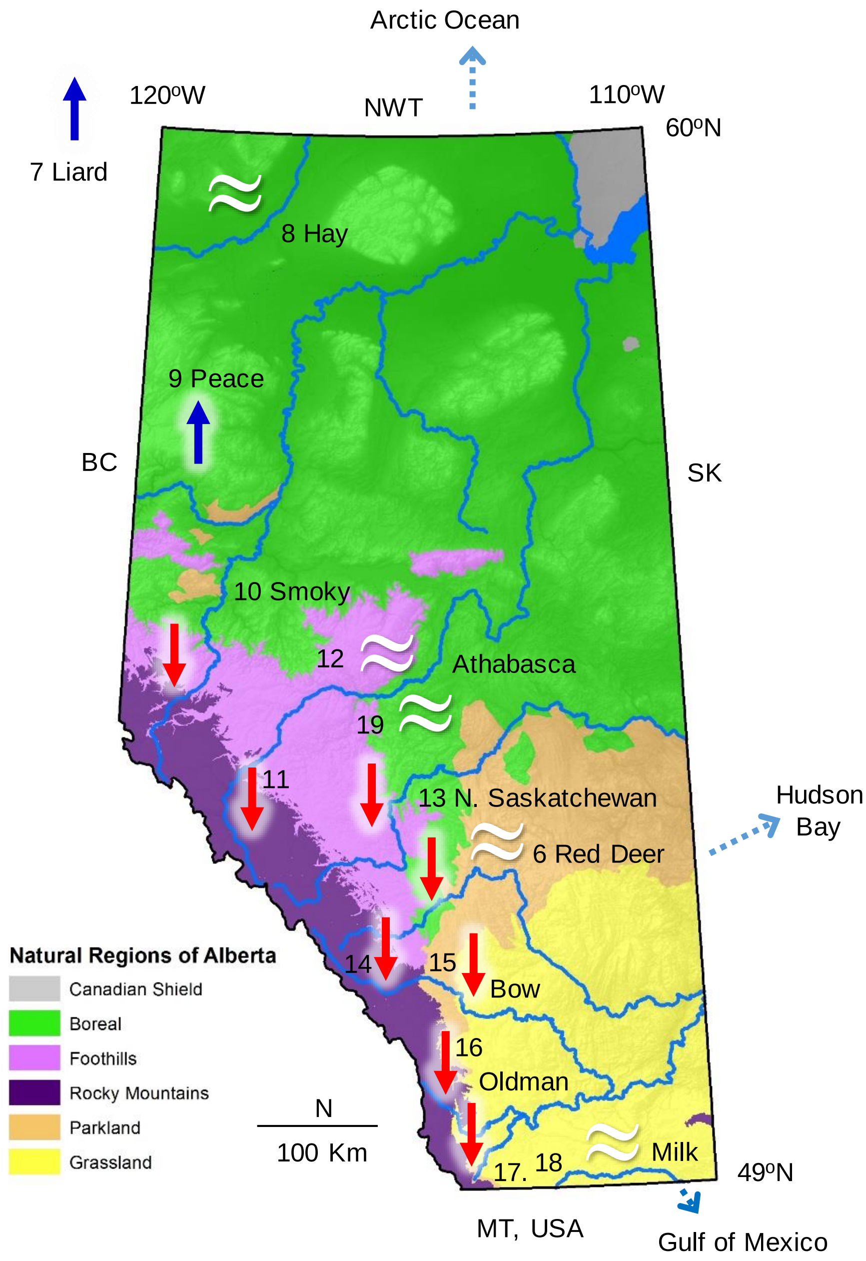
Historic Hydrology – Are floods worsening in Alberta?

We analyzed annual peak flows for rivers draining the 'hydrographic apex' of North America, the zone that provides the headwaters for rivers that flow to the Pacific, Atlantic and Arctic oceans, including the tributaries of the South Saskatchewan River Basin. Contrary to prediction from the 'intensification hypothesis', which anticipates that floods will increase due to an accelerated water cycle with global warming, peak flows have been declining along Alberta's Rocky Mountain rivers (paper #3).



The decline in peak flows probably follows from: (1) declining overall annual flows over the past century; (2) with winter warming there is an increase in the proportion of rain versus snow and this increases winter river flows and decreases snow packs; (3) with spring warming there is an advancement in the period of snowmelt, (4) the timing of peak flows is relatively unchanged and there is consequently a longer interval after snowmelt commences. These (3 & 4) reduce the snowmelt contribution to the peak and also reduce the extent of watershed saturation, decreasing runoff from rain. The consequence of (1) through (4) is the reduction in annual peak flows and there is also the subsequent decline in summer flows (5).

Our analyses have also extended northward to investigate historic patterns in annual, seasonal and peak flows for Alberta's northern rivers. We'd previously determined that annual, seasonal and peak flow have been declining over the past century for the Oldman and Bow rivers, while the Red Deer was relatively unchanged. Extending northward this latitudinal pattern continues and thus flows of the northern rivers are increasing as summarized in a figure from paper #12 (below, arrows for increase or decrease, or no change in annual flows over the past century).



4.4. Water Use and Sources

An important research objective we addressed was to determine the amount of river water (alluvial groundwater) that is required to meet the normal evapotranspiration requirements of healthy riparian cottonwood forest ecosystems.

In theory, riparian forest trees could access water from at least three potential water sources, (i) alluvial groundwater taken up by deep roots at the capillary fringe, just above the saturated soil water zone, (ii) recent summer precipitation inputs to the shallow soil layers taken up by roots active near the soil surface, and (iii) water accumulated throughout the non-saturated soil zone extending from the soil surface to the capillary fringe. Access to this third source would require active, functional roots throughout the non-saturated soil zone. The large unsaturated soil zone could accumulate and mix precipitation inputs over time, including melt water from snow, and water input from other sources, like runoff from plateaus above the river channel and water from periodic over-bank river flooding.

It is clear that cottonwood riparian forests in semi-arid western regions of North America do not receive sufficient growing season precipitation to completely support the relatively high transpiration requirements of these forests. For example, cumulative evapotranspiration in cottonwood riparian forests can exceed precipitation inputs substantially during the growing season (Fig. 4.1, 4.2). This indicates that a variable, but often substantial, portion of the water used in transpiration in riparian forest ecosystems must be supplied by alluvial groundwater or water stored in the potentially large reservoir of the unsaturated soil zone (Fig. 4.2).

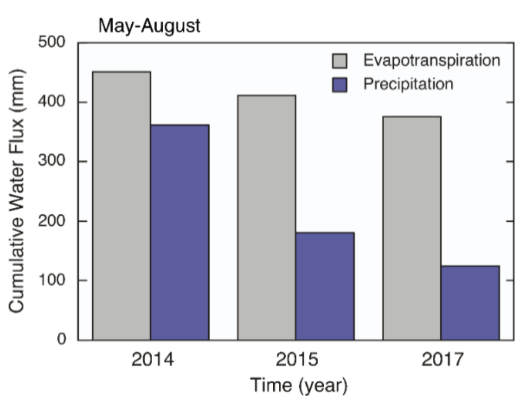


Fig. 4.1. Comparison of cumulative evapotranspiration and precipitation in a riparian cottonwood forest during May-August in three different years with contrasting environmental conditions. Evapotranspiration was measured using the eddy covariance technique Flanagan et al. (2017, #8) and Yang et al. (2019, #20). No evapotranspiration measurements were conducted during 2016.

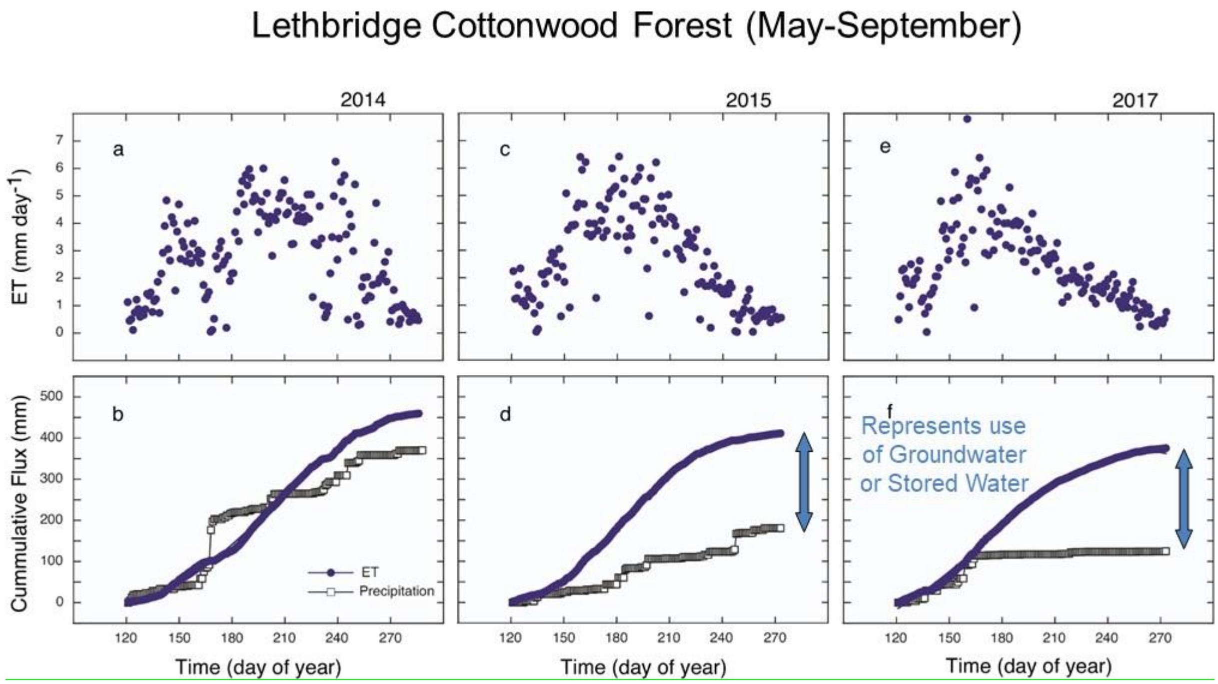


Fig. 4.2. Seasonal variation in the daily evapotranspiration (ET) rates (a,c,e) and cumulative evapotranspiration and precipitation (b, d, f) in a cottonwood forest in Lethbridge, Alberta during 2014, 2015, and 2017 (Flanagan et al. 2017, #8; Yang et al. 2019, #20).

The maximum daily ET we measured for cottonwood forest ecosystems was approximately 6 mm/day and was very similar in years with different environmental conditions (Fig. 4.2). The cumulative total ET for the May-September growing season in the cottonwood forest was also quite similar among years (varying from approximately 450 mm to 390 mm in different study years; Figs. 4.1, 4.2).

In addition to measurements of ecosystem evapotranspiration using the eddy covariance technique, we also applied stable isotope analyses to trace water source use by the cottonwood trees and two associated shrub species typical of southern Alberta cottonwood forests (*Shepherdia* and *Symphoricarpos*; Figs. 4.3, 4.4).

Our results indicated that the riparian cottonwood trees did not exclusively take up alluvial groundwater, but made extensive use of water sourced from the unsaturated soil zone. For example, the oxygen and hydrogen isotope compositions of cottonwood stem water did not strongly overlap with those of alluvial groundwater, which were closely associated with the local meteoric water line (top regression line in Fig. 4.3). Instead, cottonwood stem water $\delta^{18}O$ and $\delta^{2}H$ values were predominantly located in dual isotope plots below the local meteoric water line, forming a separate line (lower regression line in Fig. 4.3) with a slope that was indicative of water that had been exposed to evaporative enrichment of heavy isotopes. In addition, cottonwood xylem water stable isotope compositions had negative values of deuterium-excess (d-excess) and line-conditioned (deuterium) excess (lc-excess) (Fig. 4.4), both of which provide evidence that water taken up by the cottonwood trees had been exposed to fractionation during evaporation, which would be expected for water in the unsaturated soil zone. Finally, seasonal variation occurred in the lc-excess values of cottonwood stem water which would be expected for soil water exposed to cumulative seasonal evaporation effects in the shallow soil layers (Fig. 4.4).

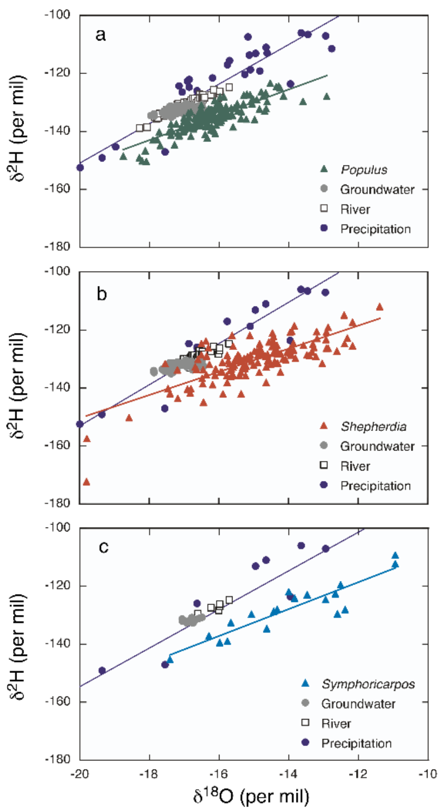


Fig. 4.3. Comparison of the oxygen ($\delta^{18}O$, ‰) and hydrogen ($\delta^{2}H$, ‰) isotope composition of precipitation (blue circles), Oldman River water (open squares), and alluvial groundwater (solid grey circles), and water extracted from plants stems. (a) Environmental waters and stem water from cottonwood trees (*Populus* sp., solid green triangles) collected during 2014-2016. (b) Environmental waters and stem water of silver buffaloberry (*Shepherdia argentea*, solid orange triangles) collected during 2015-2016. (c) Environmental waters and stem water of snowberry (*Symphoricarpos occidentalis*, solid light blue triangles) collected during 2016 (Flanagan et al. 2019; #17).

Access to water in the large storage volume of the unsaturated soil zone, in addition to water supplied from the alluvial groundwater, allows riparian cottonwood trees to have high and relatively consistent evapotranspiration rates, despite widely varying environmental conditions (Figs. 4.1, 4.2). We have estimated that the total water used in the growing season by evapotranspiration in this cottonwood forest during a dry year (2017) was supplied approximately equally from (i) alluvial groundwater, (ii) growing season precipitation, and (iii) other water stored in the unsaturated soil zone (Yang et al, 2019). Water in the unsaturated soil zone can be replenished by over-bank flooding of the adjacent river. However, the relatively low frequency of such flooding events (~ 5- to 10-year return interval), means that precipitation inputs provide the main annual input of water to the unsaturated soil zone in this region.

Only approximately 30% of maximum water holding capacity of the unsaturated soil remained two years after a major flood, and normal growing season precipitation inputs (268 ± 92 mm) are not sufficient to fill the remaining soil volume with water. This means that riparian cottonwood trees are reliant on water supplied by the alluvial groundwater in order to survive in the semi-arid region of southern Alberta. These analyses support the suggestion that riparian cottonwood forests should be much more sensitive to reduction in supply of alluvial groundwater than exposure to lower precipitation inputs during the summer growing season.

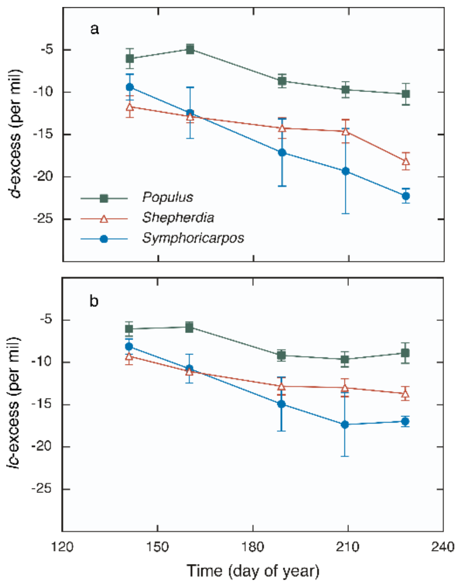


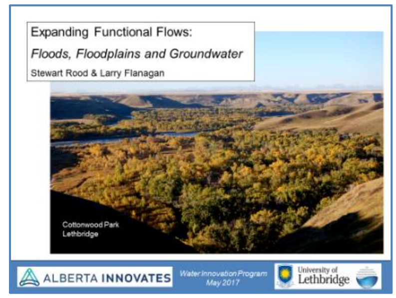
Fig. 4.4. Seasonal variation in the average (± SE) (a) deuterium-excess (d-excess) and (b) line conditioned excess (lc-excess) calculated for plant stem water values sampled during 2016; cottonwood trees (*Populus* sp., solid green squares), silver buffaloberry (*Shepherdia argentea*, open orange triangles), snowberry (*Symphoricarpos occidentalis*, solid light blue circles).

(Right) Whole ecosystem fluxes of water, carbon dioxide and methane are measured with eddy covariance flux towers. This study utilized two towers, with this permanent tower in the Bridge Grove along the Oldman River in Lethbridge. With CFI funding, we also built a unique, trailer-mounted 'riparian rover' tower that we used that mobile tower to analyze ecosystem fluxes in a floodplain woodland along the Red Deer River. (May 2015, Stewart Rood)

5. Accomplishments: Scientific Achievements & Knowledge Dissemination

5.1 Presentations

19 important presentations were made, including technical presentations at regional and international scientific conferences, broader-interest public presentations, and a presentation to the *House of Commons Standing Committee on Agriculture* (P9).

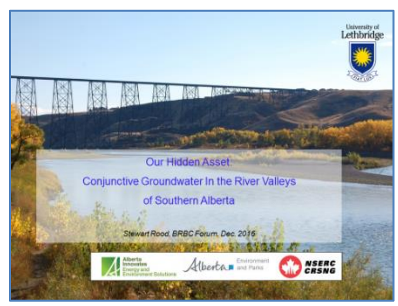


2016

P1. (Presentation 1) May 31, 2016. Stewart Rood and Larry Flanagan. Expanding functional flows - Floods, floodplains and groundwater. AI-EES Water Innovation Program Workshop, Edmonton. Presentation to ~ 75. (Functional Flows, Water Use and Floods)

P2. July 18, 2016. Stewart B. Rood and John M. Mahoney. Functional environmental flows: Science and application. Pacific NorthWest Economic Region 2016 Summit Calgary. ~ 30 in attendance. (Functional Flows)

P3. Dec. 15, 2016. Lawrence B. Flanagan, Trina E. Orchard, Gordon S.J. Logie, Craig A. Coburn, Stewart B. Rood. Water use in a riparian cottonwood ecosystem: Eddy covariance measurements and scaling along a river corridor. American Geophysical Union (AGU) Fall Meeting 2016, San Francisco, CA, USA. (Poster presentation)(Water Use)



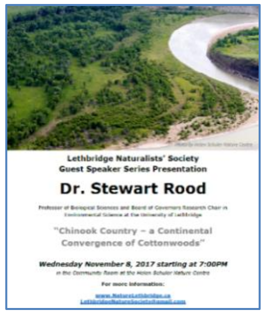
P4. Dec. 14, 2016. Stewart Rood. Our hidden asset: Conjunctive groundwater in the river valleys of Southern Alberta. Bow River Basin Council Science Forum (Strathmore, AB). ~ 100 in attendance. (Water Use)

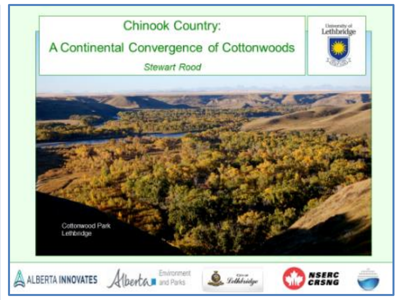
2017

P5. Apr. 7, 2017. Stewart Rood and John Mahoney. The silver lining project: Post-flood river regulation for riparian enhancement. Watershed Resiliency and Restoration Program (WRRP) Lethbridge. ~75 in attendance. (Floods and Hydrology)

P6. June 6, 2017. Stewart Rood and others. Are floods worsening from the crown of the continent? Canadian Water Resources Association National Meeting, Lethbridge. ~200 in attendance. (Floods and Hydrology)

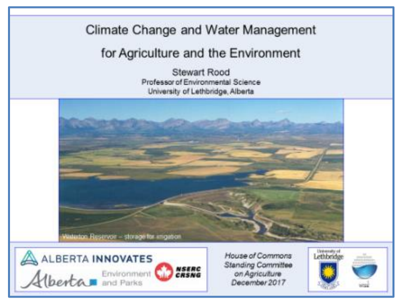
P7. Nov. 8, 2017. Stewart Rood. Chinook country - a continental convergence of cottonwoods. Public presentation hosted by the Lethbridge Naturalists Society at the Helen Schuler Nature Centre, Lethbridge. ~75 in attendance (Functional Flows)



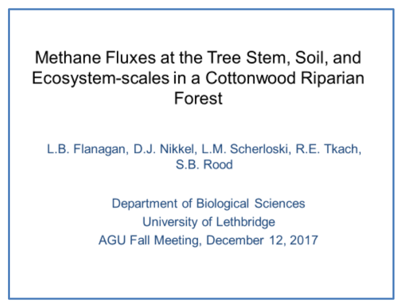


P8. Nov. 21, 2017. Stewart Rood. Looking back to prepare for the future: The St. Mary and Oldman River Dam projects. Alberta Irrigation Association annual meeting, Lethbridge. ~250 in attendance. (Functional Flows)

P9. Dec. 7, 2017. Stewart Rood. Climate change and water management for agriculture and the environment. Submission and Presentation to the **House of Commons Standing Committee on Agriculture** (the meeting was in Ottawa and I contributed by video-link). About 15 MPs, and a similar number of support staff. (Water Use)



P10. Dec. 12, 2017. Larry Flanagan and others. Methane fluxes at the tree stem, soil, and ecosystem-scales in a cottonwood riparian forest. American Geophysical Union Fall Meeting, New Orleans. (Water Use)

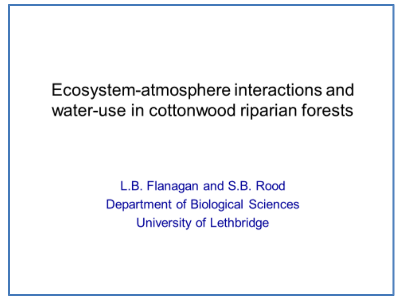


2018

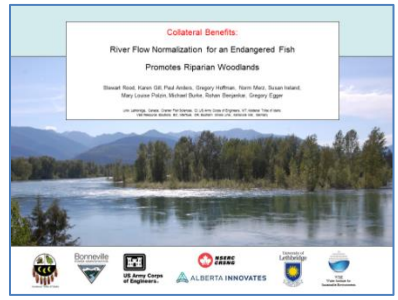
P11. Jan. 4, 2018. Stewart Rood. The parched Oldman: A century of river regulation from the crown of the continent. Keynote, banquet presentation to the Canadian Council for Fisheries Research annual meeting, Edmonton, AB. ~300 in attendance. (Functional Flows)

P12. Feb. 1, 2018. Larry Flanagan and Stewart Rood. Ecosystem-atmosphere interactions and water-use in cottonwood riparian forests. Université de Sherbrooke, Que. (Water Use)

P13. May 23, 2018. Larry Flanagan and Stewart Rood. Water-use in riparian cottonwood forests. Alberta Innovates - Water Innovation Program workshop, Edmonton. ~100 (Water Use)

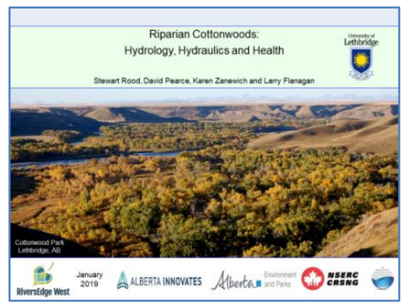


P14. May 31, 2018. Stewart Rood and others. Collateral benefits: River flow normalization for an endangered fish promotes riparian woodlands. Society of Wetlands Scientists annual meeting, Denver, CO. ~50 (Functional Flows)



2019

P15. Feb. 6, 2019 Stewart Rood, David Pearce, Karen Zanewich- and Larry Flanagan. 2019. Riparian Cottonwoods: Hydrology, Hydraulics and Health. Phoenix. Riparian Restoration Conference. RiversEdge West, Phoenix.. Invited, Plenary Speaker. (Water Use)



P16. May 8, 2019. Brenda Herbison, Mary Louise Polzin, and Stewart B Rood. Bottom-up and Top-down: Compound Influences of River Regulation and Beavers on Riparian Cottonwoods along the Duncan River, British Columbia. Regulated Rivers II: Science, Restoration, and Management of Altered Riverine Environments. Columbia Mountains Inst. Applied Ecology. Nelson, BC. Poster. (Functional Flows)

P17. May 8, 2019. Mary Louise Polzin and Stewart B. Rood. Assessing impacts of a new flow regime along the lower Duncan River, British Columbia. Regulated Rivers II: Science, Restoration, and Management of Altered Riverine Environments. Columbia Mountains Inst. Applied Ecology. Nelson, BC. Oral Presentation. Conference Proceedings paper (*R3*). (Functional Flows)

P18. May 8, 2019. Stewart Rood and others. Collateral Benefits: Common Instream Flow Needs for Fish and Forests along the Kootenai River, USA. Regulated Rivers II: Science, Restoration, and Management of Altered Riverine Environments. Columbia Mountains Inst. Applied Ecology. Nelson, BC. Poster presentation. (Functional Flows)

P19. May 9, 2019. Stewart Rood, Mary Louise Polzin and Brenda Herbison. Reservoir Regulation and Vegetation in the Draw-down and Delta Zones of the Duncan Lake Reservoir, British Columbia. Regulated Rivers II: Science, Restoration, and Management of Altered Riverine Environments. Columbia Mountains Inst. Applied Ecology. Nelson, BC, Oral Presentation. A Conference Proceedings paper (*R4*). (Functional Flows)

5.2 Publications

Publications are listed with trainees underlined, and * indicates the corresponding author. Funding sources: AB Innovates – this project; AI-EES – primarily the prior project; AEP - Alberta Environment and Parks; CC – City of Calgary; CFI – Canadian Foundation for Innovation; CPC - ConocoPhillips Canada; NSERC – Natural Sciences and Engineering Council (Canada)

Papers 1 through 4 were largely undertaken during the prior AI-EES Functional Flows project and completed with this AB Innovates project. Studies for papers 5, 7 and 8 commenced with the prior AI-EES project and were completed with this AB Innovates project. Other papers report research that was primarily undertaken during this AB Innovates project.

Journal Papers (with web-links)

2016

1. Evans, L.M.*, Kaluthota, S., Pearce, D.W., Allan, G.J., Floate, K., Rood, S.B. and Whitham, T.G. 2016. Bud phenology and growth are subject to divergent selection across a latitudinal gradient in *Populus angustifolia* and impact adaptation across the distributional range and associated arthropods. *Ecology and Evolution* 6: 4565-4581. (AI-EES, NSERC, NSF) (Functional Flows)
https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.2222

2. Hillman, E.J., Bigelow, S.G., Samuelson, G.M., Herzog, P.W., Hurly, T.A. and Rood*, S.B. 2016. Increasing river flow expands riparian habitat: Influences of flow augmentation on channel form, riparian vegetation, and birds along the Little Bow River, Alberta. River Research and Applications 32: 1687-1697. (AEP, AI-EES, NSERC) (Functional Flows)
https://onlinelibrary.wiley.com/doi/full/10.1002/rra.3018

3. Rood, S.B.*, Foster, S.G., Hillman, E.J., Luek, A. and Zanewich, K.P. 2016. Flood moderation: declining peak flows along some Rocky Mountain rivers and the underlying mechanism. Journal of Hydrology 536: 174-182. (AI-EES, NSERC) (Floods and Hydrology)
https://www.sciencedirect.com/science/article/pii/S0022169416300774

4. Rood, S.B.*, Kaluthota, S., Gill, K.M., Hillman, E.J., Woodman, S.G., Pearce, D.W. and Mahoney, J.M. 2016. A twofold strategy for riparian restoration: Combining a functional flow regime and direct seeding to re-establish cottonwoods. *River Research and Applications* 32: 836-844. (AI-EES, NSERC) (Functional Flows)
https://onlinelibrary.wiley.com/doi/full/10.1002/rra.2919

2017

5. Foster, S.G., and Rood*, S.B. 2017. River regulation and riparian woodlands: Cottonwood conservation with an environmental flow regime along the Waterton River, Alberta. *River Research and Applications* 33 (7): 1088-1097 (AB Innovates, AEP, NSERC) (Functional Flows)
https://onlinelibrary.wiley.com/doi/pdf/10.1111/rec.12654

6. Rood, S.B.*, Goater, L.A., McCaffrey, D., Montgomery, J.S., Hopkinson, C. and Pearce, D.W. 2017. Growth of riparian cottonwoods: Heterosis in some intersectional *Populus* hybrids and clonal expansion of females. *Trees* 31: 1060-1081. (AEP, AB Innovates, NSERC) (Functional Flows) https://link.springer.com/article/10.1007/s00468-017-1531-9

7. Rood, S.B.*, Kaluthota, S., Philipsen, L.J., Rood, N.J. and Zanewich, K.P. 2017. Increasing discharge from the Mackenzie River system to the Arctic Ocean. *Hydrological Processes* 31: 150-160. (AB Innovates, NSERC) (Floods and Hydrology) https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.10986

8. Flanagan, L.B.*, Orchard T.E., Logie, G.S.J., Coburn, C.A. and Rood, S.B. 2017. Water use in a riparian cottonwood ecosystem: Eddy covariance measurements and scaling along a river corridor. *Agricultural and Forest Meteorology* 232: 332-348. (AB Innovates, CPC, NSERC) (Water Use) https://www.sciencedirect.com/science/article/pii/S0168192316303793

2018

9. Benson, R.D.* and Rood, S.B. 2018. Bringing 20th century water projects into the 31st century: The case for revisiting dam operations in Alberta, Canada. *Canadian Water Resources Journal*. 43 (3): 335-346 (AEP, AB Innovates)(Functional Flows) https://www.tandfonline.com/doi/full/10.1080/07011784.2018.1455539

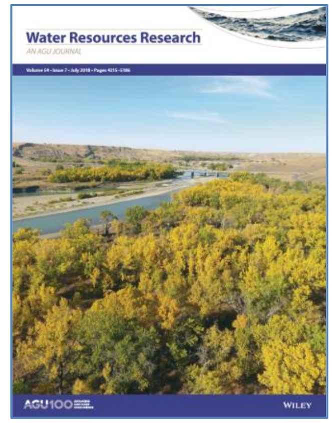
10. Foster, S.G., Mahoney, J.M. and Rood*, S.B. 2018. Functional flows: An environmental flow regime supports cottonwood growth and colonization along the Waterton River, Alberta. *Restoration Ecology* 26 (5): 921-932 (AB Innovates, NSERC) (Functional Flows) https://onlinelibrary.wiley.com/doi/pdf/10.1111/rec.12654

11. Gill, K.M., Goater, L.A., Braatne, J.H. and Rood*, S.B. 2018. The irrigation effect: How river regulation can promote some riparian vegetation. *Environmental Management*. 61 (4): 650-660 (AEP, AB Innovates, Idaho Power Co., NSERC) (Functional Flows) https://link.springer.com/article/10.1007/s00267-017-0991-4

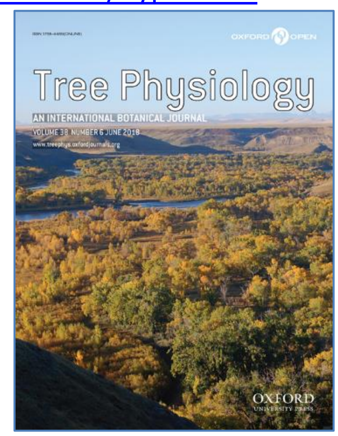
12. Philipsen, L.J., Gill, K.M., Shepherd, A. and Rood* S.B. 2018. Climate Change and Hydrology at the Prairie Margin: Historic and Prospective Future Flows of Canada's Red Deer and other Rocky Mountain Rivers. *Hydrological Processes* (AEP, AB Innovates, NSERC) 32(17): 2669-2684 (Floods and Hydrology) https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.13180

13. Philipsen, L.J., Pearce, D.W. and Rood*, S.B. 2018. Hydroclimatic drivers of the growth of riparian cottonwoods at the prairie margin: River flows, river regulation and the Pacific Decadal Oscillation. *Dendrochronologia* 51: 82-91 (AEP, AB Innovates, NSERC) (Floods and Hydrology) https://www.sciencedirect.com/science/article/pii/S1125786518300651

14. Tai, X., Mackay, D.S., Sperry, J.S., Brooks, P., Anderegg, W.R.L., Flanagan, L.B., Rood, S.B. and Hopkinson, C. 2018. Distributed plant hydraulic and hydrological modeling to understand the susceptibility of riparian woodland trees to drought-induced mortality. *Water Resources Research* 38(6) 789-800 & Cover (AB Innovates, CPC, NSF, NSERC)(Water Use) https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018WR022801



15. Zanewich, K.P., Pearce, D.W. and Rood, S.B. * 2018. Heterosis in poplar involves phenotypic stability: Cottonwood Hybrids outperform parental species at suboptimal temperatures. *Tree Physiology* 38: 789-800 & Cover (AEP, AB Innovates)(Functional Flows) https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.10986



2019

16. Franks, C.G., Pearce, D.W. and Rood, S.B. 2019. A prescription for drug-free rivers: Absorption of pharmaceuticals by a widespread streamside willow. *Environmental Management* 63 (1): 136-147 (AEP, AB Innovates, NSERC)(Functional Flows) https://link.springer.com/article/10.1007/s00267-018-1120-8

17. Flanagan, L.B.*, Orchard, T.E., Tremel, T.N., and Rood, S.B. 2019. Using stable isotopes to quantify water sources for trees and shrubs in a riparian cottonwood ecosystem in flood and drought years. *Hydrological Processes*. (AB Innovates, NSERC)(Water Use) https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.13560

18. Nielson, K.G.*, Gill, K.M., Springer, A.E., Ledbetter, J.D., Stevens, L.E., and Rood, S.B. 2019. Springs ecosystems: vulnerable ecological islands where environmental conditions, life history traits, and human disturbance facilitate non-native plant invasions. *Biological Invasions*, 21 (9): 2963-2981. (Imperial Oil Foundation, AEP, AB Innovates, NSERC) (Functional Flows) https://link.springer.com/article/10.1007/s10530-019-02025-6

19. Rood*, S.B., Kaluthota, S., Philipsen, L.J., Slaney, J., Jones, E., Chasmer, L., and Hopkinson, C. Camo-maps: An efficient method to assess and project riparian vegetation colonization after a major river flood. *Ecological Engineering*. (City of Calgary, AEP, AB Innovates, NSERC) (Floods and Hydrology) https://www.sciencedirect.com/science/article/pii/S0925857419303349

20. Yang, H., Rood, S.B. and Flanagan*, L.B. 2019. Controls on ecosystem water-use and water-use efficiency: Insights from a comparison between grassland and riparian forest in the northern Great Plains. *Agricultural and Forest Meteorology* 271: 22-32 (AB Innovates, CPC, China Scholarship Council, NSERC) (Water Use) https://www.sciencedirect.com/science/article/pii/S0168192319300929

2020

21. Rood*, S.B. and Willcocks, A. Duckling mortality at a river weir. *Canadian Field Naturalists*. In press. (AEP, AB Innovates) (Floods and Hydrology)

Manuscripts Submitted

22. Nielson, K.G., Woodman, S.G. and Rood*, S.B. Prospective impacts of oil spills on floodplain vegetation: Crude oil or diluted bitumen increase foliar temperatures, senescence and abscission in three cottonwood (*Populus*) species. *Public Library of Science 1* (*PLOS1*). Rejected with option for resubmission, under revision. (AEP, AB Innovates, NSERC) (Floods and Hydrology)

23. Sinnatamby, R.N.*, Mayer, B., Kruk, M.K., Rood, S.B., Farineau, A., and Post, J.R. Considering multiple anthropogenic threats in the context of natural variability: Ecological processes in a regulated riverine ecosystem. *Ecohydrology*. Favorably reviewed, under revision. (AB Innovates, NSERC) (Floods and Hydrology)

24. Tinschert, E., Egger*, G., Wendelgaß, J., Heinze, B., and Rood, S.B. Alternate reproductive strategies of *Populus nigra* influence diversity, structure and successional processes within riparian woodlands along the Allier River, France. *Journal Hydro-Environmental Research*. Favorably reviewed, under revision. (AB Innovates, NSERC) (Functional Flows)

Reports: Technical Reports and Conference Proceedings

R1. Rood, S.B., Kaluthota, S., Philipsen, L.J. and Zanewich, K.P. 2016. Analyzing and Projecting Post-Flood Vegetation Colonization along the Bow River through Calgary, Alberta. Report for the City of Calgary and Klohn Crippen Berger. 130 pages. (City of Calgary, AB Innovates) (Floods and Hydrology)
http://scholar.ulethbridge.ca/sites/default/files/rood/files/rood_et_al_2016_analyzing_and_projecting_post-flood_vegetation_colonization_-_sept.pdf?m=1569431218

R2. Rood, S.B. Flanagan, L.B. and Mahoney, J.M. 2016. Post-Flood River Regulation to Rejuvenate Riparian Woodlands along the Bow River, Alberta. Report for City of Calgary, Klohn Crippen Berger and Watershed Resiliency and Restoration Program. pp.33. (City of Calgary, AB Env. Parks, AB Innovates) (Floods and Hydrology)

R3. Polzin, M.L. and Rood, S.B. 2019. Assessing impacts of a new flow regime along the lower Duncan River, British Columbia. Conference Proceedings. Regulated Rivers II: Science, Restoration, and Management of Altered Riverine Environments. pp. 40-45. Nelson, BC, Canada. May, 2019.
https://cmiae.org/wp-content/uploads/Proceedings_Regulated-Rivers-II_2019.pdf

R4. Rood, S.B., Polzin, M.L. and Herbison, B. 2019. Reservoir regulation and vegetation in the draw-down and delta zones of the Duncan Lake Reservoir, British Columbia. Conference Proceedings. Regulated Rivers II: Science, Restoration, and Management of Altered Riverine Environments. pp. 165-171. Nelson, BC, Canada. May, 2019.
https://cmiae.org/wp-content/uploads/Proceedings_Regulated-Rivers-II_2019.pdf

R5. Slaney, J., Rood, S., Dick, W., and Rennie, C. 2019. The City of Calgary's river morphology risk mitigation program. E-proceedings of the 38th IAHR World Congress (9 pp). September 1-6, 2019, Panama City, Panama (City of Calgary, AB Innovates) (Floods and Hydrology)

6. Lessons Learned and Project Management

This project achievements exceeded our proposed research activities and this was partly due to an ideal research group. It involved two senior professors and collaborating faculty or government scientists as appropriate for specific components. Undergraduate and graduate students and research assistants were involved in all aspects and particular tasks would often involve two or three senior scholars and one to three trainees. This group size provided sufficient enthusiasm to keep the tasks advancing but was small enough to ensure regular interactions.

Relative to large versus small research approaches, a dichotomy arose with the initial *Alberta Ingenuity Centre for Water Research*. The University of Alberta Co-Director and engineer Dan Smith argued that research projects advance with one or two senior scholars and one or two trainees. Conversely, University of Calgary Co-Director and ecologist Ed McCauley favored larger, collaborative and interdisciplinary projects. Both research approaches have merit and following two decades of the water research programs in Alberta, I support the current *Alberta Innovates – Water Innovation Program* approach. This commonly provides support for teams of two to five researchers and additional trainees. This approach contrasts with some federal programs that provide tens of millions of $ to particular initiatives. That 'big science' approach may end up producing another granting agency rather than achieving a coordinated research collaboration.

7. Building Innovation Capacity – Highly Skilled Personnel

The funding from Alberta Innovates and the partner agencies was primarily used for salary support for the 20 trainees and research staff. Most of the participants were university students and their contributions have been recognized with co-authorships in presentations and journal papers (trainees are underlined in the listings). Following their graduations, some have taken on positions with government agencies or private industry. Others have advanced to graduate school programs at the universities of British Columbia, Cambridge, and Guelph.

Name	Level	Period	Thesis Title/Project	Status
High School Student				
Peka Mueller	High School student	2018	River regulation and water quality along the Little Bow River	BSc student, University of British Columbia
Undergraduate Students - BSc				
David Tavernini	BSc student	2016	Ecosystem resource subsidies in the Oldman River	MSc student, University of British Columbia
Dylan Nikkel	BSc student	2016-2017	Field assessment of water use and methane production	Continuing UL student
Lauren Scherloski	BSc student	2016-2017	Methane fluxes in riparian woodlands	Receptionist, Harvest Yoga Studio
Diandra Bruised Head	BSc student	2017	River resource management: Blood Tribe lands and the St. Mary Dam	Climate Change Coordinator, Blood Tribe
Nikki Colucci	BSc student	2017	River resource management: The Oldman River Dam	MSc student, University of Guelph
Joan Peterson	BSc student	2018	Biogeography of the Little Bow River	Carmangay Library Board Member
Reid Stoyberg	BSc student	2018	Effect of water content on methane and carbon dioxide fluxes in a cottonwood forest soil	Environmental Scientist, Matrix Solutions
Jessica Kuziw	BSc student	2019	Vegetation management and pipelines	Continuing UL student
Research Assistants				
Sam Woodman	Research Assistant	2015-2016	Growth and physiology of cottonwood (poplar) trees	PhD student, University Cambridge
Rachel Tkach	Research Assistant	2017	Riparian flux towers - Oldman and Red Deer Rivers	BSc student, UL

Graduate Students - MSc				
Stephen Foster	MSc student	2013-2016	Cottonwood evaluation following environmental flow implementation along the Waterton River	Hydrologist, Alberta Environment and Parks
Kayleigh Nielson	MSc student	2016-2017	Non-native plant occurrence and human disturbance at freshwater springs in Alberta, Canada	PhD student, University of British Columbia (UBC-O)
Laurens Philipsen	MSc student	2016-2017	River Regulation and Riparian Woodlands Along the Lower Red Deer River, Alberta	Research Manager, Farmers Edge
Kristian Smits	MSc student	2019	Methane production by riparian cottonwoods	Continuing UL student
Oscar Zimmerman	MSc student	2019	Modeling riparian woodland processes	Continuing UL student
Research Associates				
Kayleigh Nielson	Research Associate	2017-2018	Plant adaptations - riparian zones and springs	PhD student, University of British Columbia (UBC-O)
Karen Zanewich	Research Associate	2016-2019	Project oversight and all aspects of the research program, especially data analyses and reporting	Continuing position
Research Professor				
David Pearce	Research Professor	2016-2019	Tree physiology and forest ecophysiology	Continuing position
Visiting Scientist				
Hao Yang	Visiting Scholar	2017-2018	Controls on ecosystem water use and water use efficiency	Chinese Academy of Sciences, Beijing

8. Project Outlook – Next Steps

There are still aspects unfolding, and several important journal manuscripts are in preparation, with support from the continuing NSERC grants.

The studies of the outcomes from the implementation of functional flows were largely site-specific and in the next project we would expand the spatial scale through the application of unmanned aerial vehicles (drones) and satellite imagery. This would be suitable for river segments, larger reaches, and even whole watersheds.

With this recent Alberta Innovates project, the studies along the Waterton are relatively complete. In contrast there has been no follow-up study after 2000 along the Oldman River, despite it being an especially important river relative to the implementation of functional flows. Our studies of the Bridge Grove in Lethbridge indicate fairly complete restoration after the declining health with severely low flows in the 1980s. We expect that there would similar benefits upstream to the LNID weir near Brocket, but the condition along the newly regulated reach from the Oldman Dam to the LNID weir is largely unknown. This is an important reach that is on the Piikani Nation lands.

There is also the need to undertake studies along Willow Creek, after the Pine Coulee Project, which included an onstream dam and offstream reservoir. The lower Bow River is a severely challenged river reach due to excessive water withdrawal at Bassano Dam and demands study. We found that the lower St. Mary River had declined beyond a recoverable threshold and it is possible that the lower Bow could be similarly stressed. Partly prompted by the major 2013 floods, and benefiting from the excellent projects by the Bow River Basin Consortium that undertook the OASIS modeling and computer-aided negotiations, there may some innovative water management strategies to benefit the lower Bow River.

We are also exporting the functional flow strategy to rivers in British Columbia and dry regions of the western United States. We have established international collaborations and many of the rivers of western North America are transboundary rivers, with shared management by Canada and the USA. There are promising opportunities for changes in dam operations in association with the renegotiation of the Columbia River Treaty, with 'ecosystem health' as a priority of the Canadian and American First Nations, who are actively participating in the renegotiation.

There are also further questions related to the ecology and physiology of riparian cottonwoods and especially their vulnerability to climate change. Rising temperatures and declining summer flows would be stressful for riparian woodlands and thus environmentally informed dam operations are increasingly important. We have introduced the concept of 'resizing rivers' and with a diminished flow regime, the extent and especially width of riparian woodlands could decrease. We would work to refine the functional flow strategy to sustain future forests, while recognizing that the woodland bands would likely be narrower.

Some of the questions relate to fundamental or basic science and we have both (Rood and Flanagan) had our NSERC Discovery Grants renewed in 2019. Our NSERC funded research programs support more basic knowledge discovery and for complementary, novel application, we were pleased that our proposal for a new Alberta Innovates – Water Innovation Program grant was provisionally approved, as summarized on the following page. With this, we are confident that we will extend the findings and applications from this important and innovative Alberta Innovates project.

Alberta Innovates – Water Innovation Program – approved project

PROJECT INFORMATION	
Project Title:	Sustaining Healthy River Valleys: Health Assessment Tools for the South Saskatchewan River Basin and other Dryland Rivers of Western North America
Lead Applicant Organization:	University of Lethbridge
Registered name and business number (if applicable):	University of Lethbridge, 119279248
Project Location(s):	Primary Rivers: Southern AB: Oldman, Bow, Red Deer and South Sask. Secondary Rivers: BC and the American southwest
Project Start Date:	June 1, 2019
Project End Date:	December 31, 2022
Total Project Budget:	$534K (+$200K American collaborators)
Requested AI Funding:	$270K = $90K/year x 3 years
Project Type:	Knowledge Generation
WIP Theme (best fit):	Theme 2: Healthy aquatic ecosystems

iii. PROJECT NON-CONFIDENTIAL SUMMARY

Rivers provide the primary water resources in Alberta and elsewhere, with damming and diversion for irrigation, municipal and industrial needs. With population and economic growth, water demand will increase and a key question arises, 'how much water needs to be left in our rivers to sustain healthy aquatic ecosystems?' Answering this requires analyses of the riparian (floodplain) and instream components, but quantifying 'health' remains difficult. In this project we will advance methods to assess the health of riparian woodlands which could serve as diagnostic indicators of the broader health of river ecosystems. We will explore field-based assessments, including tracking alluvial groundwater, which is recharged from the adjacent river. We will investigate vegetation indices obtained from satellite remote sensing, including Normalized Difference Vegetation Index (NDVI) and a new metric, Near Infrared Reflectance of Vegetation (NIR_V). These should be correlated with photosynthesis and sensitive to drought stress. We will assess correspondences between the satellite vegetation indices and groundwater levels, vegetation patterns and especially, eddy covariance flux tower measurements of photosynthesis and transpirational water use. We will also examine the associations with river flows, and precipitation and temperature, which influence water supply versus demand. We will compare conditions along healthy versus degraded river reaches in the South Saskatchewan River Basin and archived satellite imaging will allow historic comparisons with field patterns. We will also apply the satellite vegetation indices and field assessments to analyze the outcomes from deliberate environmental Functional Flow regimes that were recently implemented for some regional rivers. There is substantial international interest in diagnostic indices of riparian health and we will collaborate with American scientists to assess the field and remote sensing methods for other regulated rivers in western North America, including some that have revised dam operations to conserve and restore endangered fish and wildlife, and improve ecosystem health.

9. Conclusions

We are pleased to provide this final report for the Alberta Innovates project, *Expanding Functional Flows: Floods, Floodplains and Groundwater*. As we report, there are four major achievements:

1. There was substantial ***Knowledge Discovery***, and we use the diverse rivers of the South Saskatchewan River Basin to undertake studies that reveal fundamental aspects of the hydrology and ecology or our valued river systems.

2. The increasing knowledge base provides the essential foundation for ***Novel Applications***, as we work with agencies that own and operate dams to achieve environmental sustainability, while also providing the important economic objectives that include water management for irrigation, industrial and municipal uses, and hydropower.

3. The combination of top-tier science and practical real-world application prompted the interest and support of a number of agencies, including provincial and federal partners, and industrial collaborators. This provided ***Substantial Leveraging*** of the Alberta Innovates investment, through cash and in-kind support, and with implementations of the functional flow regimes.

4. Students and research assistants were involved in all aspects of the projects and most of the funding went to salary support for the training of ***Highly Skilled Personnel***. The trainees have directly benefited as the experience has strengthened their career prospects and many have secured favorable jobs. Alberta and Canada also benefit as the trainees and researchers will be increasingly able to contribute to informed water resource management. Efficient flow regulation is essential since our regional and national rivers are challenged by increasing demands with a growing population and agricultural and industrial expansion, and as summer flows gradually decline with climate change.

(Right) A meander lobe along the Bow River at 'Hulls Wood' in Fish Creek Provincial Park. The 2013 flood expanded the point bar (the grey/brown area), which is being colonized by a new generation of balsam poplar and willows, after a prolonged interval without woodland regeneration. The birds, other wildlife, and trout along the Bow River will substantially benefit from this riparian rejuvenation. (Sept 2018, Stewart Rood)