Figure 1. The Oldman River valley in Lethbridge, 15/9/2016. Bands and patches of new cottonwood seedlings were abundant, including a dense patch in the foreground, following the favorable functional flow regimes of 2014 - 2016.

Functional Flows:
A Practical Strategy for Healthy Rivers

Project No.: AI 2068A
Final Report
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Stewart B Rood[1], Larry B Flanagan[1], Joseph B Rasmussen[1], Alice Hontela[1],
John M. Mahoney[2], Stefan W Kienzle[3], Craig Coburn[3], and Chris Hopkinson[3]

[1] Dept. Biological Sciences, University of Lethbridge; [2]Alberta Environment and Parks, Lethbridge; [2]Dept. Geography, University of Lethbridge

Executive Summary

In Alberta and most areas worldwide, rivers provide the primary water sources for human use, agricultural irrigation, and industrial development. Subsequently, a key question arises, how much water needs to be left in our rivers to sustain healthy aquatic (instream) and riparian (streamside) ecosystems? While scientists recognize that the fisheries and floodplain forests are adapted to the natural flow regime, it is quite impractical to fully restore natural flows along regulated rivers. As an alternate management strategy we are developing 'functional flows' to satisfy the environmental instream flow needs for healthy river ecosystems. These are deliberately artificial flow patterns that seek to optimize instream flows for environmental survival during low flow years, and achieve environmental enhancement in high flow years when abundant water provides management flexibility.

This AI study sought to advance the scientific foundation and the actual implementation of functional flow regimes for the different rivers of the South Saskatchewan River Basin (SSRB) in southern Alberta. Studies of regional historic hydrology revealed that due to winter warming that reduces mountain snow packs and spring warming that advances snow melt, summer flows are substantially declining and spring peaks and flood flows are also apparently declining. To understand how much water is used by floodplain forests and provide the largest knowledge gap for river basin modeling we implemented two flux towers in riparian woodlands. We worked with Alberta WaterSMART to implement a functional flow routine for the SSRB models and this revealed that implementation for the Red Deer and other rivers could be readily accomplished. Field studies along the Red Deer River indicated that the riparian woodlands are currently generally healthy, with recruitment having persisted after the implementation of Dickson Dam.

Functional flow regimes have been implemented for the St. Mary, Waterton and Oldman River Dams, and further implementation occurred during the research interval. These involved two main changes, increased minimum flows during the warm and dry late summer interval and flow ramping, gradual flow recession after the spring peak. The studies demonstrated that these were successful in promoting the colonization and growth of riparian cottonwoods and willows, thus rejuvenating the woodlands along the Oldman and Waterton Rivers, but the St. Mary River had declined beyond the point of recovery with restored flows.

The study interval included the major floods in the Bow River system and field studies revealed that this triggered a major rejuvenation of the woodlands through Calgary and downstream, after seven decades without a major flood. We developed an analytical method to correctly project post-flood vegetation establishment and this benefits woodland rejuvenation in suitable locations and also reveals hazard locations through the City of Calgary, where new riparian woodlands would impede river flows, increasing future flooding in Calgary.

With these studies, implementations, papers and presentations, the functional flow strategy has become familiar and generally embraced in southern Alberta. This novel environmental flow management strategy is also being exported to other river systems in western North America.

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4. Project Description

This major project represents an extension from studies that commenced around 1990 during the controversial Oldman River Dam Project. Prior to that, we had discovered the collapse of riparian woodlands downstream from the St. Mary Dam and the developers of the Oldman River Dam sought to avoid a similar outcome. We were thus tasked with determining: (1) what was the cause(s) of the cottonwood mortality, and (2) can woodland decline be avoided? We recruited John Mahoney as a research associate and graduate student, and we have been working on these questions since. John was recruited as the Biologist for the Oldman Dam and has subsequently advanced to his present position as the lead of dam operations for Oldman River Basin. This has been strategic and successful as we've progressively analyzed river and riparian conditions and actually altered the dam operations for the major dams in this river basin.

We extended these studies to explore the consequences of the changes in flow regime with the 'Rivers For Life' project of the Alberta Water Research Institute. During that phase we introduced the concept of functional flows and that provided the focus for this recent AI project. The overall question was, did it work? Did the changes in river flow regulation with the functional flow strategy provide measurable environmental benefit? This provided the theme for this project and there were also a number of essential and complementary questions that related to ecohydrology, the fast-growing research field that blends ecology and hydrology.

For the project, we brought together a research team from the Water Institute for Sustainable Environments (WISE) at the University of Lethbridge (UL). This research was centered in the UL Water and Environmental Science Building, which was funded by Alberta following the designation of the UL as the home for the Alberta Ingenuity Centre for Water Research. There was thus an ideal convergence of an important research topic, an impressive research facility and a strong group of faculty and students in the fields of Biology and Physical Geography.

With this structure the project pursued four overlapping research themes:

A. River and Watershed Hydrology,
B. River Flows, Riparian Woodlands and Riparian Water Use,
C. River Flows and Aquatic Health, and probably most distinctively,
D. Implementation and Assessment of Functional Flows.

After project commitment, a major natural event occurred in June, 2013, the record floods in the Bow River Basin, and extending south into the Oldman Basin. This provided a rare and ideal opportunity for the riparian studies of floods and floodplains (theme B) but challenged some of the proposed studies on the aquatic, or instream system (theme C) with the major disturbance of aquatic conditions. The floods provided both challenges and opportunities for the other themes (A and D) and we sought to capitalize on the unique study opportunities. Thus, there were changes from the original plan and overall, major advances from the post-flood studies.

5. Approach and Results ([#]s correspond to the listing of papers in Section 10)

A. River and Watershed Hydrology

Analyses of Historical River Flows in Alberta

For river flow management it is essential to understand water supplies and in addition, flow alteration from damming and diversion. The magnitude and seasonality of river flows in Alberta have also been gradually changing with climate change. We have previously analyzed historic trends in flows of Alberta's southern rivers and with this project we are advancing northward.

Flows of the Red Deer River have changed only slightly over the century [22], demonstrating less alteration than along the Bow and Oldman systems. Projections from down-scaling of global circulations models (GCMs) also suggest slight change [22]. In contrast to some prior reports that considered shorter intervals, analyses of century-long records for the Athabasca River indicate some variation with the Pacific Decadal Oscillation (PDO), but only slight overall change, with opposing trends in the mountain headwaters versus the boreal region downstream [16].

Advancing northward, annual flows of the Peace River have slightly increased over the past century and annual and seasonal flows of the Liard River, the largest Mackenzie River tributary substantially increased, producing increases in the Mackenzie River downstream [3]. Thus, (1) changes are less dramatic than previously concluded based on short-term records (partly due to PDO transitions), and (2) there are different outcomes for rivers across Alberta. Flows are declining for southern rivers, unchanged for central rivers and increasing for northern rivers. Flow seasonality is changing across the province, with earlier spring rise and often declining summer flows, which will impose stress on the aquatic and riparian ecosystems.

In contrast to earlier, simplistic predictions that global warming would amplify the water cycle and increase floods, peak flows are actually declining along some river in Alberta [6]. This reflects reduced snow packs due to winter warming, earlier and more gradual snow melt with spring warming and consequently less snow melt contribution to the major, late spring peaks.

Climate and Watershed Modeling

As a sentinel system, the Waterton watershed is now under simulation, and the future climate scenarios have been processed for two main periods: 1971-2000 (baseline) and 2041-2070. First maps of climate changes in terms of temperature changes, changes in snowfall, and potential evapotranspiration can be installed. Many climate indices can now also be calculated.

Streamflow simulations of the Drywood River, a tributary of the Waterton River, have been finalized. Historical streamflow can be replicated in terms of volumes, seasonality, shape of hydrographs, streamflow variation and exceedance probabilities. The Nash-Sutcliffe coefficient of efficiency is 0.7 for daily flows, and 0.88 for monthly flows, demonstrating strong correspondence.

This now allows for the simulation of five future climate projections for the period 2041-2070, ranging from relatively "warmer and drier" to relatively "cooler and wetter" projections. From the simulated future daily streamflow time series, critical hydrological parameters such as maximum flow, return periods, timing of spring peak, or recession rates can be calculated.

A further accomplishment is the calculation of 44 climate indices trends for the study area, including frost-free period, day of last and first frost, growing season length, and growing degree days for 0, 5 and 10°C, as well as number of both low and high temperature extremes [20].

River Basin Modelling with Functional Flows and Environmental Performance Measures

We have been working with WaterSmart, HydroLogics and other agencies to consider how Functional Flows will complement the Oldman South Saskatchewan (OSSK) Adaptation Project. We have completed the implementation of Environmental Performance Measures routines for the OASIS model for the Oldman and South Saskatchewan Rivers. The performance measures related to riparian woodlands and fisheries and have been implemented for both the Red Deer Basin sub-model and the integrated Oldman/South Saskatchewan OASIS models.

The Red Deer sub-basin model was completed and Functional Flows were implemented with routines to engage flow ramping after high flows. These were applied to the Red Deer sub-basin model and to the overall SSRB model and demonstrated that functional flows could be delivered from Dickson Dam with no cost or loss relative to other uses or objectives. Thus, it is anticipated the Functional Flows will become part of the operations regime for the Red Deer River, as is the case for the Oldman River and its Southern Tributaries.

Assessment of Additional Reservoir Storage

We worked with resources managers from Alberta Agriculture and their consultants to consider how additional storage could assist in the implementation of Functional Flows for the Oldman River Basin, and especially for the southern tributaries. With the extensive infrastructure projects already installed and due to the supply limitations and aspects including the Boundary Waters Treaty and Prairie Provinces Apportion Agreement, there would probably be limited benefit from additional storage.

The 'Storage Study' is complete and determined that the Oldman River Basin has reached a point at which further water capture and storage would have limited benefit. In low-flow years, which are most relevant for water storage, there is very little 'surplus' river flow, above the level that must be passed on to Saskatchewan as part of the Interprovincial Apportionment Agreement. The technical study has thus confirmed our prior expectation and prediction.

The Storage Study and the OSSK (Oldman South Sask) OASIS model development overlapped and this provided the first opportunity to directly compare the OASIS modeling with the Province's Water Resources Management Model (WRMM). The two models produced fairly similar outcomes for the prospective additional storage dams for the St. Mary and Belly Rivers but prompted rather different interpretations relative to the merit for the Kimball Dam, another prospective storage structure on the St. Mary River.

B. River Flows, Riparian Woodlands and Riparian Water Use

Oldman River

We installed an eddy covariance flux-tower in the floodplain forest along the Oldman River in 2013. This allowed for the rigorous analysis of water-use by the riparian woodland [4], resolving the largest unknown variable in the hydrologic models for the South Saskatchewan River Basin.

The flux tower and associated meteorological instruments were installed in 2013 and functioning over 2014 and 2015, ideally providing measurements during wet and dry years. The ecosystem water flux and energy balance closure data indicate that the data were of very high quality.

Measurements of the forest leaf area index (LAI) (total leaf area/ground area) were conducted at intervals during the growing season using several complementary techniques (radiation transmission through the tree canopy; plant harvest measurements of understory herbaceous plants; litter traps for leaf collection during autumn leaf senescence).

The total forest LAI, which reflects the area of transpirational water loss, reached a peak of 2 (leaf area ~ double the ground area), with about one-half contributed by cottonwood forest trees and the other half contributed by understory herbaceous plants, primarily grasses. A model of the seasonal change in forest functional leaf area closely approximated the field results.

For spatial up-scaling, we required inventories of the riparian woodlands and developed remote sensing techniques with multiple-spectral scanning and digital satellite imaging. We characterized the Normalized Difference Vegetation Index (NDVI)/ Leaf Area Index (LAI) relationship for the Oldman River and parameterized the Pennman-Monteith equation to compute water use even without further flux measurements. With this, we scaled up the riparian evapo-transpiration to determine water use by the cottonwood forests along the Oldman River downstream of the Oldman River Dam.

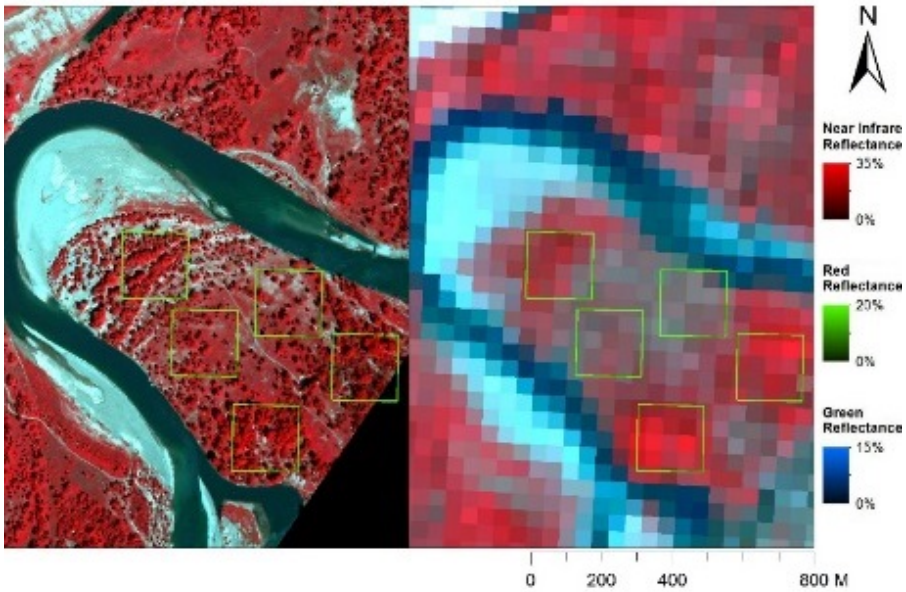


Figure 2. False-color infrared red aerial photograph (left) and digital satellite image (right) with quadrats for woodland inventory (green boxes), along the Oldman River, used to determine woodland characteristics and leaf area indices (LAI).

Following from these analyses we can provide the key information that was sought, as displayed in the figure below [4].

1. Riparian woodlands displayed a seasonal pattern of water use that peaks at about 5 mm per day in mid-summer (evapo-transpiration (ET) = evaporation from soil and other surfaces + plant transpiration).

2. Somewhat surprisingly, the seasonal water use pattern was quite consistent in wet (2014) and dry years (2015).

3. The woodlands use local precipitation and alluvial groundwater that infiltrates from the adjacent river. In dry years, the stressful years relative to the water supply and demand, the water source is primarily from river water.

4. With spatial up-scaling with remotely-sensed woodland density determinations, the amount of river water that is used by the woodlands can be fairly accurately determined. In mid-summer riparian woodlands will consume around 5% of the river flow released from the Oldman River Dam but this will more than double in low flow intervals. This is a small but significant demand, which can be input into the water balance models to contribute to the prescription of functional flows.

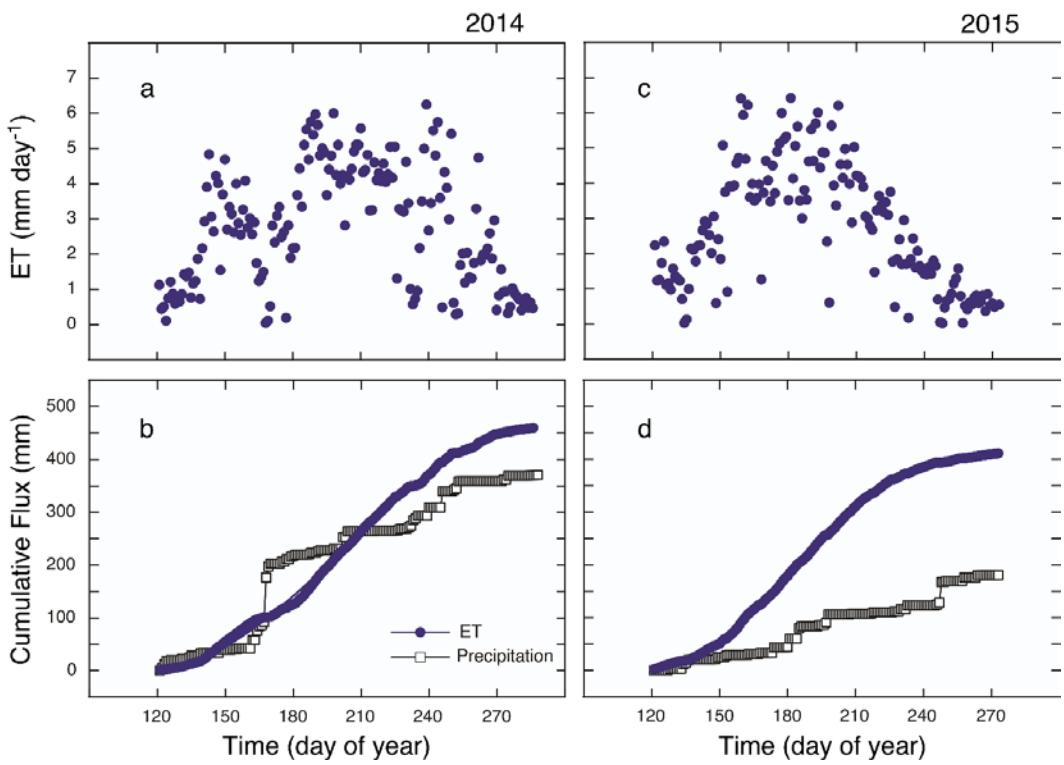


Figure 3. Seasonal patterns of riparian woodland water use (Evapo-Transpiration, top) and cumulative water use and precipitation (bottom) in wet (2014) and dry years (2015).

Red Deer River

The flux tower in the Oldman River valley was ideal to answer the key question relating to water use by riparian woodland. However, this provided data for a single site only. Fortunately, we were successful with a CFI application, which allowed for the development of $210K trailer-mounted mobile flux tower. This is a unique instrument system that can be readily deployed in riparian woodlands or other ecosystems. For these analyses, the flux tower data allow for the characterization of water and carbon exchanges and these can then be used to calibrate accurate, predictive models that rely on climate data, precipitation, temperature, insolation (sun) and wind. Thus, the mobile tower is ideal in that it can be positioned at a site for a few months allowing the model parameterization, which can then be applied after the tower is relocated.

We first positioned the mobile flux tower in a riparian woodland upstream from Dinosaur Provincial Park along the Red Deer River in the summer of 2016 and this provided initial results that confirmed the functionality, with favorable energy balance closures (below, instrument installation before the tower is tilted up). This tower will be extensively used for the next AI funded project and we were also pleased to secure a grant from Conoco Phillips Canada that allows for permanent situation of the Oldman River valley flux tower. With these two towers functioning, the Oldman tower will provide a fixed reference and the mobile tower will be positioned at various locations along the river valleys in Southern Alberta. The results from the Oldman and Red Deer River flux towers, combined with a remote-sensing strategy to characterize woodland densities, will allow for the reach-specific determinations of the seasonal water use by riparian forests. These results will contribute to the functional flow prescriptions and can be incorporated within the OASIS models for the Oldman, Bow and Red Deer Rivers. For the determination of woodland canopy characteristics we are also now using a drone to provide much higher resolution imagery than aerial photographs or satellite data (below).

Figure 4. Implementation of our unique, trailer-mounted eddy covariance flux tower, in a riparian woodland along the Red Deer River, with instrument installation in the summer of 2016. For canopy characterization we are now using a drone for high resolution imagery of the woodlands (right).

C. River Flows and Aquatic Health

The 2013 and 2014 floods impeded the proposed instream field projects but controlled environment studies were vigorous, utilizing the nationally unique UL Aquatic Research Facility. This research is especially related to contaminants with concentrations and impacts dependent on river flow patterns. Compound stresses are being investigated, including temperature, pharmaceuticals and agricultural chemicals, especially herbicides.

Figure 5. The UL Aquatic Research Facility allows rigorous and extensively replicated studies of the influences of single and combined influences on aquatic organisms, especially fish. Different water conditions and chemical concentrations are combined to assess acute and longer term impacts on growth, behavior, survival and reproduction.

In collaboration with Dr. Bryan Brooks, Fulbright Canada Visiting Research Chair in Water and the Environment at UL and an expert in the toxicology of pharmaceuticals we completed a sequence of studies to characterize key physiological thresholds for fish health. We obtained samples of the treated effluent released into the Oldman River by the Waste Water Treatment Plant in Lethbridge. The effluent was extracted and analyzed for pharmaceuticals in the Brooks lab at Baylor University in Texas.

Diltiazem (DTZ), a calcium channel blocker heart medication, has been selected as a model contaminant because unexpectedly high concentrations of this pharmaceutical were measured in the wastewater effluent released into the Oldman River. Even though DTZ has been detected in the waste water treatment plant effluent in Lethbridge and at other locations, the current understanding of the effects of this widely used pharmaceutical drug on non-target species including fish is limited to one published study on the acute toxicity of DTZ to Japanese medaka, a tropical fish, and to *Daphnia* (Kang et al. (2005) *Kor. J. Env. Health Sci*. 31; Fekete-Kertesz et al. (2016) *Carpath J. Earth Env. Sci*. 11). Our study assessed the effects of DTZ on the cardiovascular function of a cold-water fish species, the rainbow trout. This exploratory study provided some potentially highly relevant findings, suggesting that DTZ might have a significant effect on the cardiovascular responses of the fish to hypoxia.

To better characterize fish responses to trace level aquatic pharmaceuticals, we have developed and validated several new bioassays, including measures of heart rate, electrocardiogram and ventilation rate. The interactions of multiple flow-related stressors, specifically changes in water concentrations of contaminants and changes in temperature and oxygen content, on the physiological performance and health of fish were subsequently investigated.

We primarily used rainbow trout (*Oncorhynchus mykiss*) as a model test species under laboratory exposures mimicking summer and winter conditions in the river. We developed and validated a suite of performance indicator measures linked to the cardiovascular function, to assess the effects of DTZ in rainbow trout under summer and winter conditions of temperature and oxygen saturation. These measures include oxygen consumption of the fish, electrocardiogram and heart rate, hemoglobin content of blood, hematocrit and blood cell counts, and ventilation rates. The contaminant concentrations, water temperatures and oxygen levels are all flow dependent and thus ideal for consideration within the functional flow strategy.

With Brooks, we also surveyed moderately saline streams and lakes for harmful toxic algae, with special emphasis on *Prymnesium parvum*. Dr. Brooks' lab has world class expertise in the identification, culture and analysis of the effects of this and other toxic algae.

Figure 6. The aquatic toxicology module in the UL Aquatic Research Facility is unique and permits the manipulation of environmental conditions in addition to deliberately altering the water chemistry with dissolved contaminants. The larger tanks also allow larger fish.

Transitioning to the river system, we are developing remote-sensing tools to benefit the study of the aquatic environments. We have been using LiDAR (Light Detection And Ranging) for the riparian research and have now used multi-spectral LiDAR that includes a green laser system, which penetrates clear water allowing for bathymetric mapping (river beds).

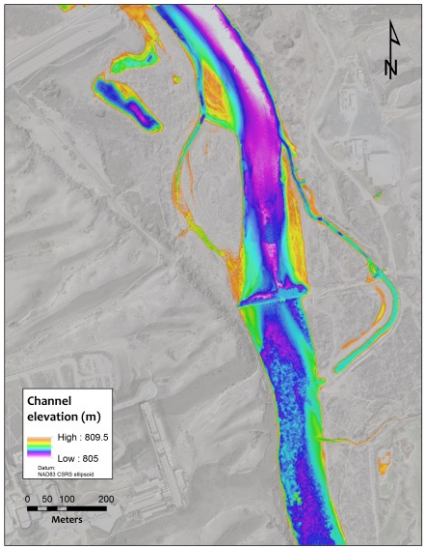


Figure 7. Mapping of bed of the Oldman River as it flows over the Lethbridge weir (line in middle), as determined with bathymetric LiDAR. The river flows northward (up) and the UL is situated at the lower left corner in the image.

D. Implementation and Assessment of Functional Flows for Rivers of the South Saskatchewan River Basin (SSRB)

In the fields of river science and river restoration the most influential current paper and concept is the *Natural Flow Paradigm* (Poff et al. (1997) *BioScience* 47). This recognizes that the essential physical processes and the life histories of the aquatic and riparian plants and animals are adapted to, and dependent upon, the natural pattern of river flows, with seasonal variation within each year and interannual variation across years. However, while this may provide an insightful conceptual foundation, it is entirely impractical to fully restore natural regimes to most regulated rivers. Further, with impacts from land-use developments, plant and animal invasions, and climate change, even if all dams and diversions were removed, riverine ecosystems would not return to their pre-development state.

As a practical alternative to the natural flow regime, we and others have developed environmental flow regimes, regulated flow patterns that continue to support the essential hydrogeomorphic processes and the life histories of riverine organisms (Richter and Thomas (2007) *Ecology and Society* 12; Merritt et al. (2010) *Freshwater Bio*. 55). The aquatic and riparian ecosystems will differ from those of a century ago but the objective is to develop healthy ecosystems, those are self-sustaining, resilient and support the favored communities of aquatic and riparian organisms, which provide the ecosystems services that we rely on (Arthington et al. (2010) *Freshw.Bio*.55).

Our particular environmental flow strategy is the functional flow approach [1,9,18]. This evolved from research that investigated river flows and riparian ecosystems and the strategy also benefits fish and the aquatic components. The approach recognizes that the water resource management opportunities vary dramatically in low-flow versus high-flow years and correspondingly prescribes very different patterns for low, normal and high-flow intervals.

In low-flow periods, the emphasis is on survival of the vulnerable plants and animals and this provides a very artificial regime with water storage during the spring run-off and delayed release to provide sufficient flows in mid- to late summer when warm and dry conditions are stressful for fish and floodplain forests. In normal years, a fairly natural flow pattern is provided and the emphasis is on growth of the riverine organisms. In the periodic high-flow years, the seasonal pattern is provided with high spring flows that provide the essential physical disturbance to create new streambank sites for the colonization of riparian cottonwoods and willows and flushing of river beds to clear and replenish spawning gravels for fish.

During the AI project, we worked to expand the implementation of functional flows for different tributaries in the South Saskatchewan River Basin (SSRB) and also worked to determine the impacts from the prior and ongoing implementations. The study interval provided very high-flow years in 2013 and 2014 and a very low-flow year in 2015 thus offering opportunities for the high- and low-flow components of the functional flow regimes.

Oldman River

Components of the functional flow strategy were first implemented for the Oldman Dam and this has now become standard practice for this system [2]. Monitoring indicates that this is succeeding in providing environmental conservation while also allowing water withdrawal for irrigation, municipal and industrial use.

Figure 8. Flooded riparian cottonwoods in June, 2013. While the major flooding was exceptionally destructive and costly for the Bow and Elbow Rivers through Calgary and the Highwood River through High River, following repetitive prior floods, Lethbridge was almost entirely relocated out of the Oldman River valley after 1953. Consequently the 2013 flood provided very little damage or cost.

St. Mary River

Draining Glacier Park, Montana and flowing northward to join the Oldman River near Lethbridge, the St. Mary River has supported the most intensive irrigation complex in Canada and is the most extensively utilized river in the South Saskatchewan River Basin. After a century of damming and diversion, around 99% of the riparian cottonwoods had died by 1990, when functional flows commenced with a tripling of the minimum flow requirement. Flow ramping was implemented after the 1995 flood and subsequently in a few years in the 2000's. However, these floodplain forests were too degraded and without parental trees there was almost no seed source and subsequently, almost no seedlings.

As a very novel but desperate strategy we combined a recruitment flow regime with direct seeding through the spreading of imported seeds and sticking of branches with maturing seeds, thus provide progressive release of about two weeks. This produced new seedlings at the release sites, confirming that the lack of seedlings was due to the lack of seed source [9]. The new seedlings grew but were progressively thinned with some mortality due to drought stress, substantial mortality due to browsing and trampling by cattle and sheet and finally, due to browsing by deer. This twofold strategy of flow management and direct seeding was thus demonstrated as a promising but costly approach and grazing management would be essential for success. While the woodland collapse was irreversible, the functional flow regime has benefited the riparian willows and the rainbow trout population has also rebounded.

The St. Mary River continues to provide an interesting and instructive case study and the dramatic collapse of the riparian woodlands has demonstrated the importance and vulnerability and the of these floodplain forests.

Waterton River

While the riparian woodlands along the St. Mary River had passed an irreversible threshold, the nearby Waterton River was only dammed in 1964 and thus didn't have the same extensive history of damming and diversion. Along with the implementation of the Oldman River Dam around 1990, there were changes in the flow patterns for the existing St. Mary and Waterton Dams, including about a three-fold increase in the legislated minimum flows. Flow ramping, gradual post-flood recession commenced after the 1995 flood and has been provided in some subsequent years.

In marked contrast to the permanent collapse of riparian woodlands along the St. Mary, following the functional flow regime, the riparian woodlands along the Waterton River have rebounded and may now be as prolific as in the 1880s, when woodlands were mapped and photographed. Thus, the Waterton River, like the Oldman River, demonstrated a major benefit from the functional flow regime [1, 18]. Similar to both the Oldman and St. Mary Rivers, the functional flow regime also benefitted riparian willows and very probably the trout populations.

Bow River

Between the AI project proposal and launch there was a very significant river event with the major floods of 2013; these provided one of the most costly natural disasters ever in Canada. The flood was destructive along the Highwood River through the Town of High River, and especially along the Elbow and Bow Rivers through Calgary, with flooding impacting the downtown zone.

The major flood disturbance along the Bow River provided a unique opportunity along that river through and below Calgary. Unlike the Oldman and Red Deer River systems, the Bow River reach has had peak flows attenuated by an extensive sequence of hydroelectric dams upstream from Calgary, these are owned and operated by TransAlta. After decades in which the channel and banks have been rather static, the 2013 flood along the Bow River produced extensive new and barren gravel bars [25]. This provided an opportunity for riparian rejuvenation along the Bow River.

Following from the major interest in consequences from the 2013 Bow River flood, we were successful with the Alberta Environment and Parks Watershed Resiliency and Restoration Program (WRRP) proposal, *Post-Flood River Regulation for Riparian Enhancement* and we are partners in the City of Calgary *Calgary Rivers Morphology and Fish Habitat Study*. These supported complementary activity, further leveraging the research enabled by the AI grant.

These projects sought to determine the patterns of riparian woodland colonization after the major flood, with two opposing objectives. For the WRRP project, there is an interest in optimizing woodland rejuvenation after a prolonged interval that lacked cottonwood colonization. Conversely, the City of Calgary sought to avoid woodland encroachment into the channel through the vulnerable downtown zone and especially at bridges or other constrictions. Such woodland development would impede channel conveyance, elevating future flood levels.

To address these two components, we developed a novel methodology to project riparian woodland development [25]. The outcomes are 'camo-maps' (these resemble camouflage) that coordinate river stage (elevation) and flow patterns and vegetation colonization and succession. An illustration below displays the projected vegetation patterns for the complex island bar upstream of the Crowchild Trail Bridge.

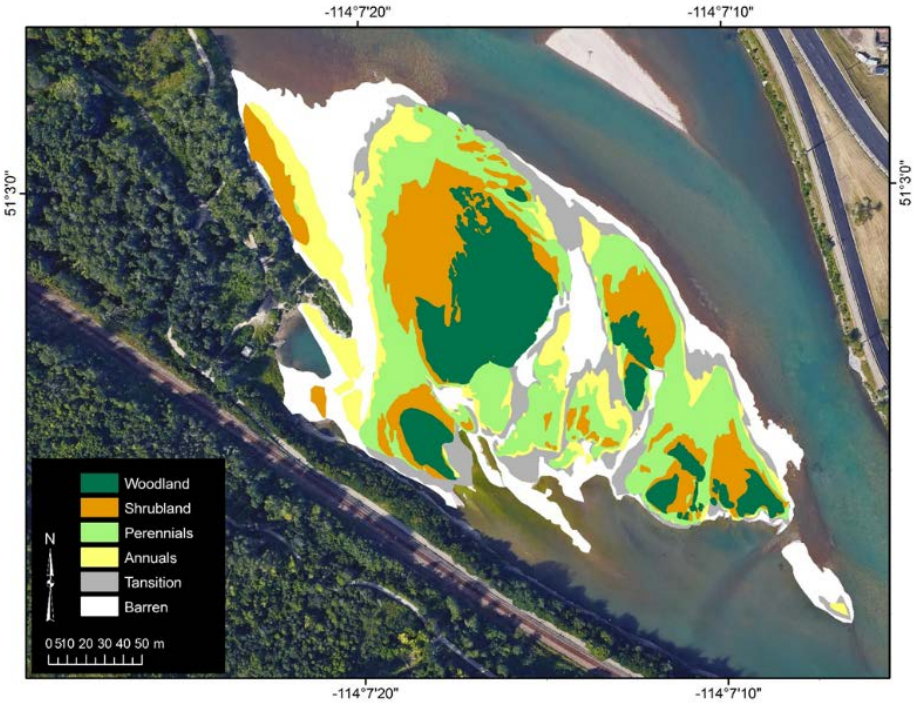


Figure 9. A 'camo-map' projection of vegetation development on the Crowchild Trail island bar complex. If the treed woodlands were permitted to develop, this would impede future flood flows raising the flood stage and overtopping the banks onto Memorial Drive and also increasing the bank erosion along that roadway and through the Crowchild Trail Bridge, immediately downstream. This is consequently regarded as a hazard location for riparian woodland development.

A second hazard location was recognized downstream of the Centre St. Bridge. This bar will be excavated, resulting in the first manipulation site as the City of Calgary will scrape the surface down to an elevation that excludes woodland development. This will avoid development of a balsam poplar grove that would increase overbank flooding near Downtown Calgary.

Figure 10. The newly formed gravel bar downstream from the Centre St. Bridge in Downtown Calgary. The green band includes abundant balsam poplar seedlings and if allowed to grow this would provide a woodland grove that would impede future flood flows. Consequently, this zone will be excavated to lower the surface below the survivable elevation for trees and shrubs.

Highwood/Little Bow Rivers

The Highwood/Little Bow Project was the second dam development after the Oldman River Dam Project, which prompted changes in environmental impact assessment and project planning. Like the Oldman Dam project and the subsequent Pine Coulee project along Willow Creek we were contracted with the Highwood/Little Bow project to contribute to the operations strategy and we recommended the key functional flow components of sufficient mid-summer flows and flow ramping, followed by gradual post-peak recession. This project was novel in that water was diverted from an expanded structure and canal in the Town of High River and that allowed *increasing* the diversion of water into the Little Bow River. This flow augmentation contrasted with flow reduction that is typical with river damming and diversion.

Following the implementation of the functional flow strategy along the Little Bow River between the canal from the Highwood River and the new Twin Valley dam and storage reservoir, the river and riparian vegetation responded as we predicted [8]. The increased and seasonally appropriate flow regime promoted obligate riparian vegetation and especially willows (*Salix* species), as well as the facultative riparian shrub wolf willow (*Elaeagnus commutata*, not a true willow). Following the increase in riparian shrubs, riparian birds have increased in abundance and richness (number of species).With the augmented flow regime the channel widened and the aquatic conditions benefitted from dilution of the inputs from adjacent livestock production and wastewater from a major meat processing plant near High River.

Figure 11. The upper reach of the Little Bow River, below High River. Flow augmentation, with a seasonal pattern applying the functional flow strategy has succeeded in allowing riparian willows to increase, creating habitat for birds and other wildlife. This case study confirmed the direct linkages between river flow regime, channel form, riparian vegetation and wildlife.

Red Deer River

Following from the collaborative work with the OASIS modeling for the Red Deer River, the operators are now more aware of the prospect for implementing Functional Flows and adjustments to operations are advancing. This component has progressed throughout the project and was complimented by the WaterSMART river basin modeling and 'Computer-assisted negotiation' (CAN), that produced overwhelming support for the functional flow strategy.

We were also interested in the current status of the riparian woodland cottonwood processes and populations and analyses of aerial photographs and field studies were undertaken during the project [23, 24]. These were consistent in suggesting favorable outcomes, indicating that woodland regeneration has persisted after the construction of the Dickson Dam. Thus, the riverine systems are reasonably healthy but the implementation of functional flows should further benefit the aquatic and riparian systems and increase their resilience and capacity to cope with the inevitable floods and drought.

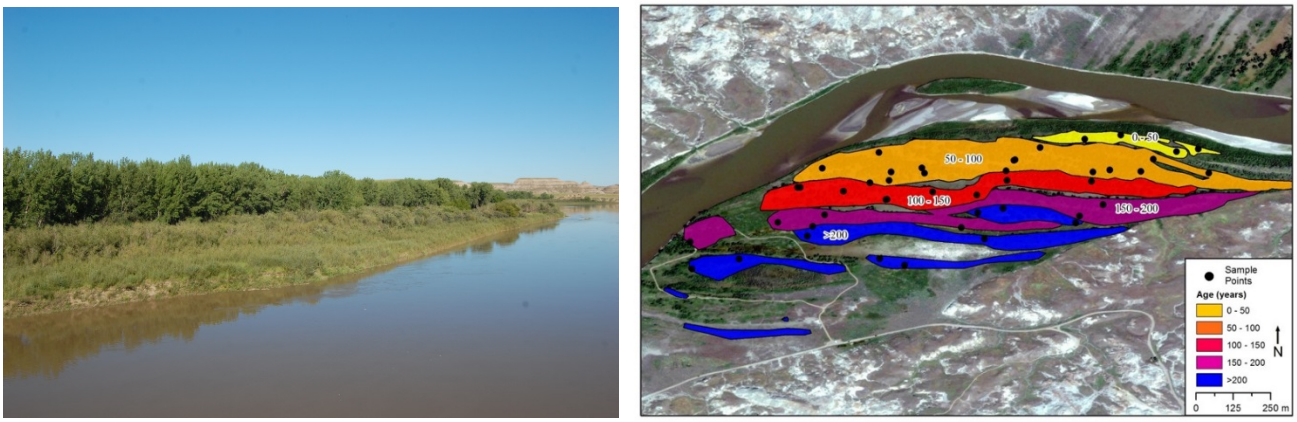


Figure 12. The Red Deer River upstream of Dinosaur Provincial Park displays relatively healthy riparian woodlands in zones that are not heavily grazed (left). Along this reach cattle grazing provides the more severe impact while the colonization of riparian cottonwoods and willows has persisted after the upstream Dickson Dam was implemented (right). Fairly minor refinements to the operation strategy for that Dam are recommended and particularly flow ramping, followed by gradual post-peak recession. This would benefit the riparian and aquatic ecosystems without any additional water commitment of management cost – the operators have indicated that they were unaware of the importance of that flow component.

For comparison, the recent flows of the Red Deer, Bow and Oldman Rivers display different seasonal patterns with the favored gradual flow ramping along the Oldman and more erratic flows along the Bow and especially Red Deer River (below). Refinement to provide flow ramping should be very feasible along all three rivers and, based on the favorable results for rivers in Alberta and elsewhere, would benefit the riparian and aquatic ecosystems.

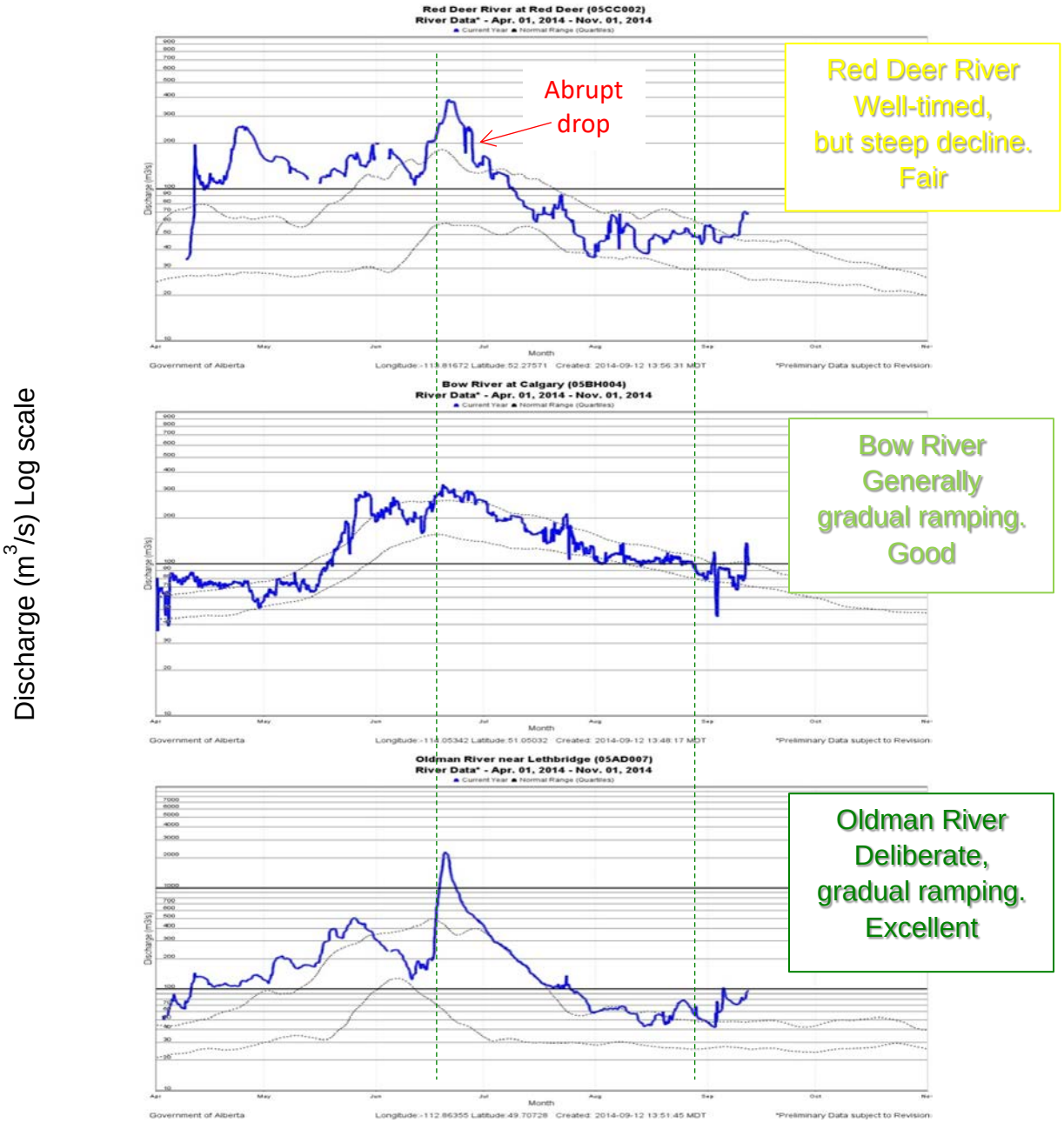


Figure 13. Flows of the three major tributaries of the South Saskatchewan River Basin in 2015. The progressive, gradual flow reduction along the Oldman River is recommended with the functional flow strategy and relatively minor refinements to dam operations along the Red Deer and Bow Rivers could provide a similar regime.

6. Relevance and Impact

This research program has substantial and direct influence on river resource management in southern Alberta. The initial motivation was associated with the Oldman River Dam Project following the strong desire by the Province and public to maintain the rich and biodiverse riparian woodlands downstream. These provide extensive ecological services, and doubly so in the prairie region where trees are naturally restricted to river valley floodplains. The riparian woodlands along the Oldman are globally unique since four different *Populus* species extend from the four ordinal directs to reach the limits of their ranges. With this overlap, there is extensive hybridization, expanding the genetic and habitat diversity. While this hybrid swarm provides valued woodlands that provide the regional focus for wildlife, supporting three-quarters of the regional bird species, hybrid poplars also provide the fastest growing trees in temperate regions and this natural diversity will contribute to future fast-growing hybrid poplars.

With the Oldman River Dam Project and following the dramatic collapse of the riparian woodlands downstream of the St. Mary Dam, we were tasked with two questions: (1) what was the cause(s) of the cottonwood mortality, and (2) can woodland decline be avoided? We have now answered those questions, as the mortality was the result of drought stress from insufficient instream flows in the summer and abrupt flow reductions that lead to faster water table recession than can be tracked by the elongating cottonwood roots. Fortunately, this stress is not the inevitable consequence of river damming but is instead the consequence of the pattern of dam operation and downstream flow management.

It is considered that environmental restoration effectively provides proof of ecological understanding and this was the case for the implementation of functional flows in the Oldman River Basin. Following the completion of the Oldman River Dam and implementation of the flow regime that we recommended, the riparian woodlands recovered from the decrepit condition in the 1980s, when the Lethbridge Northern Irrigation District (LNID) weir diverted the vast majority of the flow resulting in river dewatering in the summer. This stressed the riparian woodlands and degraded aquatic conditions as the river water warmed and became depleted of dissolved oxygen. With the implementation of the Oldman Dam, the abundant spring flow could be stored in the reservoir and gradually released downstream to compensate for the irrigation withdrawal at the LNID weir. The flows through Lethbridge in mid-summer of low flow years were increased twenty-fold, and the flow ramping benefited the riparian and aquatic ecosystems, without any sacrifice in irrigation withdrawal. Subsequently, the Oldman River ecosystems downstream from the LNID weir were dramatically *improved* as a result of the Oldman River Dam Project.

These studies indicate that environmental recovery also occurred downstream from the Waterton Dam, with the functional flow regime that was implemented. Despite a favorable functional flow regime, these studies found that the riparian woodlands downstream from the St. Mary Dam did not recover. These were too far gone, and with almost no parental trees, there was very little seed source for recolonization, and the (stressed) deer and beaver in the valley browsed the sparse colonization patches that did establish. There is thus reversibility with slight environmental degradation but severe collapse is irreversible with the cost-effective management tool of flow regime.

These studies clarified the general health of the riparian woodlands along the Red Deer River, although cattle grazing can cause severe local impacts. The modelling of the Red Deer River Basin revealed that the implementation of functional flows should be easy and will require rather slight commitment, without cost. During the projects, the operators of that dam indicated, 'we just didn't know about environmental flows'. Following from the successful woodland conservation and restoration along the Oldman and Waterton Rivers and along some other rivers in the western United States, we are confident that the functional flow strategy will be applicable and successful with minimal cost along many dammed rivers in semi-arid regions. One of the most dramatic river restorations involved the application of the 'Oldman Model' for flow management of the Truckee River that drains Lake Tahoe and flows into the Nevada desert. This prompted a feature article in the *New York Times*, a cover-page article in *BioScience* and has been included in numerous biology and ecology text books. Our view is that if we can restore a river in the water-starved Nevada desert, it should be quite feasible to apply the functional flow strategy for many more dammed rivers around the world, with riparian poplars (cottonwoods) being predominant riparian trees in riparian woodlands around the Northern Hemisphere.

We regard these successful river restorations as 'good news' stories that are especially welcomed in the current context with vast environmental concerns related to the abuse of many ecosystems and the global challenge of climate change.

7. Overall Conclusions

The key and important conclusion from the collective studies is that, 'it works', the implementation of functional flows is feasible and successful relative to riparian conservation and restoration. The specific prescription of flow patterns relies on sufficient characterization of a river and its flow regime and the project contributed to a number of analytical and management tools, such as the mass balance river basin models, including the Province's Water Resources Management Model and OASIS-SSRB model developed by Hydrologics and Alberta WaterSMART along with many partners including our group. It is also notable that two of the primary scientists on that project were our former students, Mike Nemeth and Ryan McDonald, and along with many papers, reports and presentations, the training of university students is one of the most important deliverables from the research program.

The research is well advanced with confident outcomes for the Oldman and Waterton Rivers and still advancing relative to the Bow River system. The Red Deer system is in good health even with the recent flow regime and it should be easy to undertake refinements to avoid the abrupt and somewhat irregular flow changes through the summer.

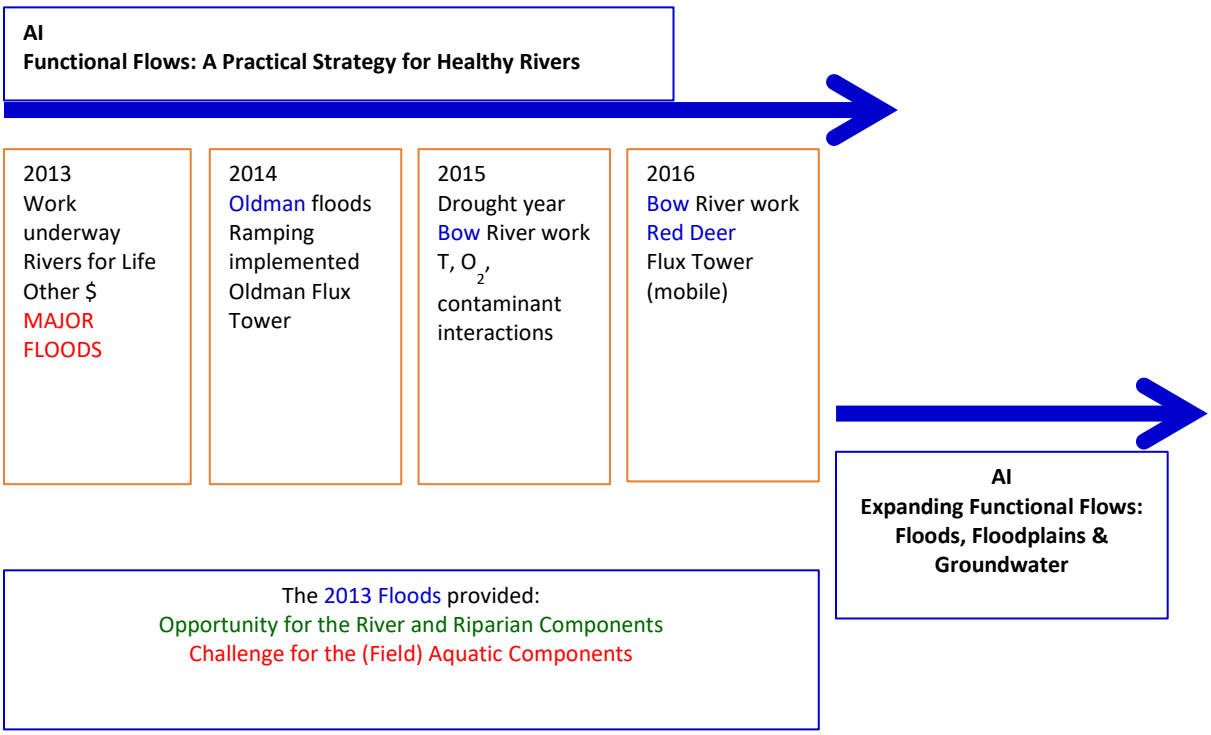
Thus, many of the questions are resolved relative to the river channel, floodplain and riparian woodlands but the coordination with the aquatic ecosystem and cool water fish is less developed.

8. Next Steps

There are still about a dozen or more journal papers to be completed from the prior studies. The collaborative projects along the Bow River system are continuing. As indicated, there has been an extension of the riparian water use components with the unique mobile, trailer-mounted eddy covariance flux tower and we are expanding these studies to include the potent greenhouse gas, methane, as well as tracking water and carbon dioxide. There is a need to better understand the interactions between surface water in the river and the adjacent alluvial groundwater and we are studying isotopic compositions of water with both $^{1/2}H$ and $^{16/18}O$. As well, the consequences from the 2013 and 2014 flood flows are still emerging.

While the research is thus continuing, further implementations will be pursued and it would be appropriate to extend the applications to other dry regions such as with British Columbia's Okanagan River system and for many rivers in the western United States. We are involved in studies along the Snake and Kootenai rivers, with collaboration with the agencies that own and operate the large hydroelectric dams. There are also novel and instructive applications in Nevada with continuing studies of the Truckee River and a new study along the Walker River.

A major factor in the near future will be the likely modifications to existing hydroelectric dams and the installation of new dams such as Site C on the Peace River. This provides a strategy to increase renewable 'green power' and reduce reliance on thermal generation with coal fired power plants. However, while hydropower is renewable, major river dams have substantial economic and environmental costs. Specifically for the Site C project, the environmental impacts from that dam will largely be downstream in Alberta and some of the principles from southern Alberta will extend to the river, riparian and aquatic processes in the wetter boreal regions of central Alberta.



9. Communications Plan

There are three key 'audiences' for our work: (1) scientists and engineers, (2) water resource managers, and (3) the interested and informed public. We have been active in communicating with all three groups and will extend these communications in the future.

Scientists and Engineers

For scientists, a primary communication strategy involves reporting in peer-reviewed journal papers. We have already produced about 25 published papers and submitted manuscripts, and anticipate another dozen from the research program. We publish in well-regarded international journals and our work is substantially cited, demonstrating impact.

We also provided many presentations at scientific conferences and organized two conferences. We organized a major special session at the 5th World Restoration Congress in Madison, WI in October 2013 and invited prominent river scientist from around the world. Following from this, a special issue of the journal *Ecohydrology* was published in 2015.

The second conference was of the Society for Environmental Toxicology and Chemistry, at the University of Lethbridge in June 2013. This attracted participants primarily from western Canada, with faculty, students and government scientists. Plenary lectures were presented by Wendell Koning (Alberta Environment), Kelly Munkittrick (COSIA - Canadian Oil Sands Innovation Alliance) and Greg Goss (University of Alberta). Additionally, Dr. K. Munkittrick also delivered a short course, 'Design of field monitoring and research programs', which was well received and strengthened our links with COSIA.

River dam operations actively involve engineers and these often have different communication approaches than academic scientists. Technical reports are often involved and smaller, focused meetings rather than major conferences. We have had numerous meetings with engineers and especially with the Bow River projects have worked closely with engineers with consulting companies and with the City of Calgary, with multiple meetings at the City's Water Centre.

Similarly, we have participated in multiple smaller meetings with engineers and resource managers with Alberta Environment and Parks and the Irrigation Division of Alberta Agriculture and Forests.

Water Resource Managers

This project greatly benefited from the excellent meetings and analyses undertaken by Alberta WaterSMART. This involved the extension of the OASIS modeling that commenced for the Oldman River Basin and extended to the Bow River prior to this project. Ideally, the modeling continued northward to provide a focus on the Red Deer River Basin during this project and we were active participants in those activities, including the Computer Aided Negotiation (CAN) sessions. With the Red Deer project, we worked with Ryan McDonald, Mike Nemeth and Mike Sheer to code and implement the functional flow strategy and we contributed to the development of the riparian and fish Performance Measures. That modeling initiative returned to the south

with the Oldman South Sask. Adaptation Project and we were again very active in that and the functional flows strategy was assessed as part of the study of expanded storage options.

This was an ideal and synergistic interaction as we provide some scientific and technical expertise and WaterSMART undertook the organization of the meetings that were well-attended by the key partners in the management of the South Saskatchewan River Basin, including Red Deer, Bow and Oldman sub-basins. With the numerous interactions, the WaterSMART and Hydrologics groups became very familiar with the functional flow strategy and have provided strong support in their reports and recommendations.

We anticipated a 'Functional Flows manual' that would be led by Dr. John Mahoney of Alberta Environment and Parks (AEP), the lead scientist and operations manager who oversaw the actual implementation of functional flows in the Oldman River Basin. As part of this project, John was seconded from AEP to work at the UL on papers and the manual. However, due to 2013 floods, the secondment was very short as he was called back to AEP to serve as the lead for post-flood dam operations. The functional flows manual has been delayed but we do anticipate completion. Dr. Mahoney provided a synthesis of the Functional Flow implementation at the Pacific NorthWest Economic Region 2016 Summit and this will provide the core content for the manual.

While the manual has been delayed, the actual implementation along the dammed tributaries in the Oldman River Basin has now become regularized. Thus, reporting is lagging but implementation has been accelerated during the project.

The Interested and Informed Public

Following from the Water For Life program, the Province established the Watershed Public Advisory Councils (WPACs) that provide a blending of public outreach and inputs into river resource management. A number of graduates from our UL program have been hired by the WPACs, including past or current executive directors of the Oldman, Red Deer and South Saskatchewan (SEWA) WPACs. We have been active with the WPACs and have provided presentations and advisement to these three WPACs as well as the Bow River Basin Council. Promoting communication and interaction between the public and experts is a priority for the WPACs and this has been ideal for our functional flows program.

We have also provided public presentations off campus and academic presentations on campus such as for the UL Water Talks. We have had other interactions such as contributing to the Conoco Phillips Canada Earth Day event and we have also had media coverage including articles in the Calgary, Red Deer, Lethbridge and Medicine Hat newspapers and on television and radio, including multiple interviews on CBC radio.

Scientific Achievements

Journal Papers

Published and In Press (Trainees underlined; additional funding sources (AEP - Alberta Environment and Parks (previously Alberta Environment or AESRD), AWRI - Alberta Water Research Institute, CPC - Conoco Phillips Canada, NSERC; *corresponding author)

2017

1. Foster, S.G, S.B. Rood*. 2017. River regulation and riparian woodlands: Cottonwood conservation with an environmental flow regime along the Waterton River, Alberta. *River Research and Applications* (in press) (AI, AEP, NSERC)

2. Rood, S.B.*, L.A. Goater, D. McCaffrey, J.S. Montgomery, C. Hopkinson and D.W.Pearce. 2017. Growth of riparian cottonwoods: Heterosis in some intersectional *Populus* hybrids and clonal expansion of females. *Trees* (doi: 10.1007/s00468-017-1531-9) (AEP, AI, NSERC)

3. Rood, S.B.*, S. Kaluthota, L.J. Philipsen, N.J. Rood and K.P. Zanewich. 2017. Increasing discharge from the Mackenzie River system to the Arctic Ocean. *Hydrological Processes* 31: 150-160. (AI, AWRI, NSERC)

4. Flanagan, L.B.*, T.E. Orchard, G.S.J. Logie, C.A. Coburn and S.B. Rood. 2017. Water use in a riparian cottonwood ecosystem: Eddy covariance measurements and scaling along a river corridor. *Agricultural and Forest Meteorology* 232: 332-348. (AI, CPC, NSERC)

2016

5. Evans, L.M.*, S. Kaluthota, D.W. Pearce, G.J. Allan, K. Floate, S.B. Rood and T.G. Whitham. 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, NSERC, NSF)

6. Rood, S.B.*, S.G. Foster, E.J. Hillman, A. Luek and K.P. Zanewich. 2016. Flood moderation: declining peak flows along some Rocky Mountain rivers and the underlying mechanism. *Journal of Hydrology* 536: 174-182. (AI, AWRI, NSERC)

7. Peters, D.L.*, D. Caissie, W.A. Monk, S.B. Rood and A. St. Hilaire. 2016. An ecological perspective on floods in Canada. *Canadian Water Resources Journal* 31: 288-306.

8. Hillman, E.J., S.G. Bigelow, G.M. Samuelson, P.W. Herzog, T.A. Hurly and S.B. Rood*. 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, AB Water Research Institute, AI, NSERC)

9. Rood, S.B.*, S. Kaluthota, K.M. Gill, E.J. Hillman, S.G. Woodman, D.W. Pearce and J.M. Mahoney. 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, NSERC, AWRI)

2015

10. Dew, W.A., A.A. Hontela, S.B. Rood and G.G. Pyle.* 2015. Biological effects and toxicity of diluted bitumen and its constituents in freshwater systems. *Journal of Applied Toxicology* 35: 1219-1227. (primarily funded by a different AI project)

11. Egger, G., E. Politti*, E. Lautsch, R. Benjankar, K.M. Gill and S.B. Rood. 2015. Floodplain forest succession reveals fluvial processes: A hydrogeomorphic model for temperate riparian woodlands. Journal of Environmental Management 161: 72-82. (Bonneville Power Administration, NSERC, AI)

12. Herbison, B., M.L. Polzin and S.B. Rood*. 2015. Hydration as a possible colonization cue: Rain may promote seed release from black cottonwood trees. *Forest Ecology and Management* 350: 22-29. (AI, BC Hydro, NSERC)

13. Herbison, B. and S.B. Rood*. 2015. Compound influences of river damming and beavers on riparian cottonwoods: A comparative study along the Lardeau and Duncan Rivers, British Columbia, Canada. *Wetlands* 35: 945-954. (AI, NSERC)

14. Kaluthota, S., D.W. Pearce*, *L.M.* Evans, M.G. Letts, T.G. Whitham and S.B. Rood. 2015. Higher photosynthetic capacity from higher latitude: Foliar characteristics and gas exchange of southern, central and northern populations of *Populus angustifolia*. *Tree Physiology* 35: 936-948. (AI, NSERC, NSF)

15. Rood, S.B.*, S. Bigelow, M.L. Polzin, K.M. Gill and C. Colburn. 2015. Biological bank protection: Trees are more effective than grasses at resisting erosion from major river floods. *Ecohydrology* 8: 772-779. (AI, NSERC)

16. Rood, S.B.*, G.W. Stupple and K.M. Gill. 2015. Century-long records reveal slight, ecoregion-localized change in Athabasca River flows. *Hydrological Processes* 29: 805-816. (AI, AWRI & NSERC)

17. Tiedemann, R.B.* and S.B. Rood. 2015. Flood flow attenuation limits floodplain forest reproduction: An experimental test along the Boise River, USA. *Ecohydrology* 8: 825-837. (AI, NSERC)

Manuscripts Submitted or in Final Preparation

18. Foster, S.G., K.M Gill. J.M. Mahoney and S.B. Rood*. Functional flows: An environmental flow regime supports cottonwood growth and colonization along the Waterton River, Alberta. *Restoration Ecology* (AI, NSERC)

19. Gill, K.M., L.A. Goater, J.H. Braatne and S.B. Rood*. The irrigation effect: How river regulation can promote some riparian vegetation. *Oecologia* (Idaho Power Corp, NSERC, AI)

20. Kienzle, S.W. Has it become warmer in Alberta? Mapping trends of temperature climate indices for the period 1950-2010 across Alberta, Canada. *The Canadian Geographer*

21. Pearce, D.W.*, S.G. Woodman, M.G. Letts and S.B. Rood. Morphology and gas exchange of native intersectional *Populus* hybrids in response to soil water deficit. *Oecologia* (AI, AEP, NSERC)

22. Philipsen, L.J., K.M. Gill, A. Shepherd and S.B. Rood*. Historic and prospective future flows of the Red Deer River and its headwater tributaries. *Can. J. Water Resources* (NSERC, AWRI, AI)

23. Philipsen, L.J and S.B. Rood*. Cottonwood recruitment and streamflow management along the lower Red Deer River, AB. E*nvironmental Management* (AI, AEP, NSERC)

24. Philipsen, L.J. and S.B. Rood*. Cottonwood growth, climate, and streamflow management along the lower Red Deer River, AB. *Forest Ecology and Management* (AEP, AI, NSERC)

Technical Reports

These were required by our contract funding partners and are very useful as they provide much more comprehensive presentations than are allowed for the shorter journal papers. We expect a sequence of journal manuscripts to advance from these technical reports and the analyses are already thorough and complete, which should expedite completion of the follow-up papers.

25. Rood, S.B., S. Kaluthota, L.J. Philipsen and K.P. Zanewich. 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.

26. S.B. Rood and J.M. Mahoney. 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. 33 pages.

27. M.-L. Polzin, B. Herbison and S.B. Rood. 2017. DDMMON#8-1 Lower Duncan River Riparian Cottonwood Monitoring Year 7 Annual Report (2016). Report for BC Hydro. 52 pages.

Conference and Other Presentations

2016

Jan. 14 - Stewart Rood, presentation to the City of Calgary, Water Engineering Group, *Analyzing and Projecting Post-flood Vegetation Colonization along the Bow River through Calgary, AB.* Technical meeting - 10 in attendance.

Feb. 3 - Stewart Rood, *Functional Flows: A Practical Strategy for Healthy Rivers*, River Restoration Northwest, Skamania, Washington. (Invited plenary speaker) ~ 300 in attendance.

Feb. 4 - Stewart Rood, *Novel Floodplain Forests: Diversity and Adaptability of Riparian Cottonwoods*, River Restoration Northwest, Skamania, Washington. Symposium speaker. ~ 250 in attendance.

Feb 12 - S.W. Kienzle. *Trends of Climate and Weather Extremes Across Alberta for the Period 1950 - 2010*. Alberta Beef Producers AGM 2016. Calgary, AB. (Invited presentation)

Feb. 18, 2016 - Laurens Philipsen and S. Rood, *Analyzing and projecting post-flood vegetation colonization along the Bow River through Calgary, AB.* Bow River Basin Council Science Forum, Mount Royal University. ~ 100 in attendance.

May 11 - S.W. Kienzle. *Global Change: Alberta's Climate Change Mapping Project*. School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal. Pietermaritzburg, South Africa. (Invited three-hour seminar)

May 30 & 31 - Stewart B. Rood. *Expanding Functional Flows - Floods, Floodplains and Groundwater*. AI Water Innovation Program Workshop, Edmonton. Presentation to ~ 75.

June 6-10 - S.W. Kienzle. *High-resolution mapping of climate indices and their trends across Alberta, Canada, for the period 1950 to 2010*. The 13th International Meeting on Statistical Climatology, Canmore, Alberta. (Oral presentation)

July 18 - Stewart B. Rood and John M. Mahoney. *Functional Environmental Flows: Science and Application*. Pacific NorthWest Economic Region 2016 Summit Calgary. ~ 30 in attendance.

July 27 - S.W. Kienzle. *Climate Change Between 1950 and 2010, and What It Means for Growers*. Lethbridge and District Horticultural Society. (Invited presentation)

Nov. 16 - S.W. Kienzle. *Did It Really Get Warmer in Alberta between 1950 and 2010?* Public presentation at the Galt Museum, Lethbridge. (Invited presentation)

Dec. 15 - 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)

Kienzle, S.W. *How Did The Climate Change between 1950 and 2010 and What Does It Mean?* Public lecture at the Lethbridge Public Library. (Invited presentation)

2015

Feb. 15 - Stefan Kienzle, *Calculation and Mapping of Climate Indices Trends for Alberta, Canada*. Pietermaritzburg, South Africa - Seminar Series of The African Centre for Global Change and Water Resources Research (UNESCO Water Centre). (Invited speaker)

Apr. 12-17 - Stefan Kienzle, *Spatial Downscaling and Correction of Precipitation and Temperature Time Series to High Resolution Hydrological Response Units in the Canadian Rocky Mountains*. European Geophysical Union Conference, Vienna, Austria. (Invited presentation)

Apr. 29 - Stefan Kienzle. *Building a Basis for Water Resources Planning in Alberta using Hydrological and Crop Models and Climate Indices*. Ludwig-Maximilians-University, Munich, Germany - Seminar Series at the Department of Geography. (Invited presentation)

May 6&7 - Stewart Rood. *Functional Flows: A Practical Strategy for Healthy Rivers*. Selkirk College, Castlegar, BC - Regulated Rivers: Environment, Ecology and Management Conference (RR:EEM Conference). (Poster)

May 6&7 - Brenda Herbison and Stewart Rood. *Cottonwood and Beaver Interactions Under Two Flow Regimes: Comparing the Free-flowing Lardeau River and the Regulated Lower Duncan River, in Southeastern British Columbia*. RR:EEM Conference. (Oral presentation)

May 6&7 - Norm Merz, Paul Anders, Rohan Benjankar, Dwight Bergeron, Brian Bieger, Michael Burke, Gregory Egger, Timothy D. Hatten, Charlie Holderman, Stewart Rood, Bahman

Shafi, Scott Soults, Philip Tanimoto, Alan Wood and Elowyn Yager. *Kootenai River Floodplain Ecosystem Operational Loss Assessment*. RR:EEM Conference. (Oral presentation)

May 6&7 - Mary-Louise Polzin and Stewart B. Rood. *Effects of Damming and Flow Stabilization on Riparian Processes and Black Cottonwoods along the Kootenay River*. RR:EEM Conference. (Oral presentation)

May 6&7 - Mary-Louise Polzin, Brenda Herbison, Mike Miles, Alf Leake, Eva-Maria Boehringer and Stewart B. Rood. *The Opposite River: Assessment of an Environmental Flow Regime along the Duncan River, British Columbia*. RR:EEM Conference. (Poster)

June - A.G. Keller, A. Manek, B. Brooks, G. Pyle and A. Hontela. *Effects of Multiple Stressors (Diltiazem, Temperature, and Hypoxia) on the Behavioural and Physiological Performance of Rainbow Trout (Oncorhynchus mykiss)*. Calgary, AB - Society of Environmental Toxicology and Chemistry - Prairie Northern Chapter (SETAC-PNC), 6th Annual Meeting. (Poster)

Sept. 24 - Stewart Rood, *Functional Flows: A Practical Strategy for Healthy Rivers*, Dept. Ecology and Environmental Science - Umeå University, Sweden. (Invited seminar)

2014

Mar. 24 - J.M. Mahoney, S.B. Rood, K.M. Gill, S. Foster, E. Hillman, L. Philipsen. *Floods, Floodplains and Functional Flows in Southern Alberta*'. Canadian Water Resources Association (CWRA) Alberta Conference, Calgary AB. (S. Rood - Oral presenter for plenary session) ~ 150 people in attendance.

Mar. 25 - S.G. Foster, E.J. Hillman, K.M. Gill, L. Philipsen, J.M. Mahoney and S.B. Rood. C*omplex Interactions: Flooding along the Highwood and Little Bow Rivers*. CWRA Alberta Conference, Calgary AB. (S. Foster and E. Hillman co-oral presenters) ~ 50 people in attendance.

Mar. 25 - L. Philipsen, K. Gill, S. Foster, E. Hillman, J. Mahoney and S. Rood. *Floods and Flows along the Red Deer River, Alberta*. CWRA Alberta Conference, Calgary AB. (L. Philipsen - oral presenter) ~ 50 people in attendance.

May 13 - Stewart Rood, Laurens Philipsen and John Mahoney. *Functional Flows: A Practical Strategy for Healthy Rivers - The Red Deer River*. WaterSmart launch for the Red Deer River Modeling Project, Red Deer AB. (S. Rood oral presenter) ~ 40 people.

May 26-28 - S.W. Kienzle and E. Wheaton. *Modelling Climate Impacts on Agro-Ecosystems*. Canadian Association of Geographers Congress / IRIACC Workshop. Brock University, St. Catherines. (Invited presentation)

June 7 - S.W. Kienzle. I*s it really getting warmer in Alberta?* Public lecture at the University of Lethbridge. Exploration Expo.

Nov. 17 - Stewart Rood, Laurens Philipsen and John Mahoney. *Post-Flood River Regulation for Environmental Benefit. WaterSMART*. SSRB Water Modelling Project - Red Deer River Workshop. (Invited presentation) ~50 people in attendance.

Nov. 19 - Stewart Rood, Karen Gill and John Mahoney. *Back from the Brink: River Restoration in Southern Alberta*. Kanai Environmental Summit, Standoff. (Invited presentation) ~150 people in attendance.

Dec. 12-17 - S.W. Kienzle. *Calculating Climate Indices, Simulating Water Resources and Crop Modelling under Climate Change Conditions in Three Watersheds in Alberta and Saskatchewan*. International VACEA (Vulnerability and Adaptation to Climate Change in the Americas) workshop, Puerto Varas, Chile. (Invited presentation)

2013

May 29 - Stewart Rood. *The Oldman River Basin - A Global Centre for Biodiversity and Management of Riparian Cottonwoods*'. Canadian Food Inspection Agency, Animal Diseases Research Institute, Lethbridge, AB (Invited seminar presentation) ~ 50 people in attendance.

June 7 - Carmen Franks, David Pearce, Alice Hontela, and Stewart Rood. *Phytoremediation of Pharmaceuticals with Sandbar Willow*. SETAC - PNC (Society of Environmental Toxicology and Chemistry - Prairie Northern Chapter Annual Mtg.), University of Lethbridge AB. (S. Rood - poster presenter) ~ 100 participants at the meeting.

Students and other Trainees

Student Name (current position)	Supervisor	Project (completed date)
BSc Project		
Megan Brown	A. Hurly	Bird diversity & riparian woodland structure
Kayla Johnson	A. Hurly	Riparian vegetation diversity and habitat
Neena Jordan	S. Rood	Additional water storage - Oldman Basin
Kelsey Lank	S. Rood	Provincial policy regarding river management and flooding
Colby Morris	L. Flanagan	Riparian ecosystem water use for the Oldman River valley and its relation to instream river flow and summer precipitation (Sept-Dec 2014)
Jason Palardy (GIS analyst with Farmers Edge)	S. Kienzle	Processing of climate data for hydrological simulations
Jordon Polson	S. Rood	Prospective Elbow River Dam
Tyler Tremel	L. Flanagan	Analysis of isotopic signature in cottonwood and *Shepherdia* stem water to determine water source (Sept-Dec 2015)
Stefan Visentin (Grad Student U Ottawa)	S. Rood	Cottonwood foliar characteristics
Samuel Woodman	S. Rood	Riparian impacts from an oil spill - Red Deer River

BSc Honours Thesis		
Kelsey Lank (Law school, UC)	S. Rood	Flood mitigation and management in Southern Alberta
Kayleigh Nielson (Graduate studs., UL)	S. Rood	Riparian vegetation responses to crude oil
MSc Thesis		
Kayleigh Nielson	S. Rood	Effects of human disturbance on vegetation in riparian ecosystems (ongoing)
Laurens Philipsen	S. Rood	Modeling & functional flows along the Red Deer River (Apr 2017)
Charmaine Bonifacio (GIS & Hydrology Consultant)	S. Kienzle	Developing ACRU Utilities for Modelling Future Water Availability: A Case Study of the Oldman Reservoir Watershed, AB (Oct 2016)
Stephen Foster (Hydrologist, EP)	S. Rood	Cottonwood Evaluation Following Environmental Flow Implementation Along the Waterton River, AB (Apr 2016)
Antonio Keller	A. Hontela & G. Pyle	Effects of multiple stressors on fish
Colin Langhorn (GIS & Hydrology Analyst,Leth.Res.Ctr.)	S. Kienzle	Simulation of Climate Change Impacts on Selected Crop Yields in S. Alberta (Dec 2015)
Gordon Logie	C. Coburn	Impact of Spatial Resolution on Riparian LAI Modelling Using Remote Sensing (Apr 2016)
Trina Orchard	L. Flanagan	Water Requirements of a Southern Alberta Riparian Cottonwood System (Aug 2015)
Evan Hillman	S. Rood	The Effects of River Flow Augmentation on the Channel Form, Vegetation and Riparian Birds of the Little Bow River, Alberta (Sept 2014)
Post-Doctoral Fellow		
Aditya Manek	A. Hontela & G. Pyle	Physiology & toxicology in aquatic systems
Research Assistants ([1]post-BSc) and Associates ([2]post-MSc)		
Markus Mueller[1] (imaging technician, Leth. Regional Hospital)	S. Kienzle	Integrated & historic and-use & hydrology modeling

Evan Hillman[2] (Research associate,AB Agriculture and Forestry)	S. Rood	Flow augmentation along the Little Bow River - manuscript published (Jan-Jul 2015)
Soba Kaluthota [2] (Instructor, Leth. College)	S. Rood	Impact of bitumen on riparian vegetation
Tyler Tremel	L. Flanagan	(1) Studies of tree and shrub water-source use based on stable isotope measurements, and (2) Studies of cottonwood forest leaf area index along the Oldman River in southern Alberta (May-Aug 2015)
Caitlin Pelletier[1]	L. Flanagan	Cottonwood forest leaf index determination
Emily Wilton[2]	L. Flanagan	Cottonwood forest leaf index determination (May-Aug 2015)
Gordon Logie[1] (Remote sensing scientist at Farmer's Edge)	L. Flanagan	Studies of cottonwood forest leaf area index along the Oldman River in southern Alberta (May 2015-Jul 2016)
Tyler Tremmel	L. Flanagan	Studies of tree and shrub water-source use based on stable isotope measurements (May - Aug 2016)
Stephen Foster[2]	S. Rood	(1) River Regulation and Riparian Woodlands: Cottonwood Conservation with an Environmental Flow Regime along the Waterton River, AB and (2) Functional Flows: An Environmental Flow Regime Supports Cottonwood Growth and Colonization along the Waterton River, AB (Apr-Mar 2016)
Karen Zanewich[2] (UL research associate)	S. Rood	River hydrology & riparian ecophysiology