AN ECOLOGICAL RESPONSE MODEL FOR THE CACHE LA POUDRE RIVER THROUGH FORT COLLINS

APPENDIXES

ECOLOGICAL RESPONSE MODELING TEAM

DECEMBER 2014

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APPENDIX A: ABBREVIATED BIOS FOR ERM TEAM MEMBERS (LISTEDALPHABETICALLY)

Gregor Auble is a research ecologist with the U.S. Geological Survey at the Fort Collins Science Center. Greg has more than 30 years of experience as an ecologist in the areas of ecological modelling, wetlands, and riparian ecosystems. For the last 20 years, his work has focused on responses of western riparian vegetation to flow alteration, channel modification, and herbivory. His studies have encompassed formal models projecting likely future vegetation as well as long-term field studies at sites including the upper Missouri, Gunnison, upper Green, Judith, Marias, and Illinois rivers. Greg earned a BA from Indiana University and a PhD in ecology from the University of Georgia. He holds professional certifications of Senior Ecologist from the Ecological Society of America and Professional Wetland Scientist from the Society of Wetlands Scientists.

Daniel Baker is a research scientist at Colorado State University (CSU). In the summer of 2012 Dan completed a postdoctoral fellowship at Johns Hopkins University, working with the National Science Foundation-funded National Center for Earth Surface Dynamics and the Intermountain Center for River Rehabilitation and Restoration based at Utah State University. He completed his PhD in civil and environmental engineering in 2009 at CSU, with a focus on river engineering and stream restoration. Dan's research focuses on the interaction between physical and biochemical processes in streams, the effects of flow extraction on stream geomorphology and sediment dynamics, and the application of Geographic Information Systems (GIS) technology to evaluate reach-scale conditions from digital elevation models. Other current projects focus on developing urban stream restoration guidance with the USACE and monitoring post-fire sediments and aquatic insects on the Poudre River.

Kevin Bestgen is the director of the Larval Fish Laboratory in the Department of Fish, Wildlife, and Conservation Biology at Colorado State University, where he is also a senior research scientist and faculty member. He has conducted research on ecology of stream fishes in the western U.S. for the past 30 years and focuses on flow and temperature needs of fishes and their conservation and restoration in altered stream systems. He has conducted biannual monitoring of fishes in Front Range streams, including the Poudre River, since 1992.

Brian Bledsoe is a professor of Civil and Environmental Engineering at Colorado State University. Brian has more than 25 years of experience as an engineer and environmental scientist in the private and public sectors, including more than 20 years of experience in stream and wetland restoration. Brian's research and teaching are focused on watershed and river processes at the interface of hydrology and aquatic ecology. He has worked in the private sector as a consulting engineer and surveyor, and for the state of North Carolina as a stream and wetland restoration specialist and nonpoint source program coordinator. Brian has served as a peer reviewer on recovery programs for the Platte and San Juan Rivers, the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP), as well as on numerous large-scale restoration projects including the Everglades and Louisiana coastal areas. Brian is a licensed professional engineer in Colorado and North Carolina.

Boris Kondratieff is a professor of entomology and director of the 3-million specimen C. P. Gillette Museum of Arthropod Diversity at Colorado State University (CSU). His current interests include insect biodiversity surveys of wild lands and other landscapes, especially military lands; aquatic insect ecology; taxonomic revisions and descriptions of new or poorly known species, especially Ephemeroptera (mayflies), Plecoptera (stoneflies), and Diptera (flies); forensic entomology; and management and curatorial work in the museum he directs. He has published 200 peer-reviewed scientific papers and coauthored four books. He currently teaches six or seven different courses in bioagricultural sciences and pest management at CSU during an academic year. He received his PhD from Virginia Tech in 1982.

Mark Lorie is a water resources planner with Abt Associates in Bethesda, Maryland. He specializes in collaborative planning and decision-making processes for water resources management, decision-support modeling, and water resources policy analysis. Mark started his career with the Institute for Water Resources of the USACE and gained expertise in planning principles, multi-objective theory, decision-support modeling, and facilitation methods while working on major studies around the country. He played a key role in USACE's Shared Vision Planning (SVP) water management effort for the International Lake Ontario–St. Lawrence River Study, and supported districts and state agencies in implementing SVP for reservoir operations, water supply and other purposes. Mark worked for two years to improve water management processes in the Potomac River Basin before becoming an independent consultant. He led the SVP process for water supply projects in northern Colorado in connection with Clean Water Act permitting, the first study of its kind in the nation. Mark has played a key role in developing a national community of practice on methods such as SVP and has worked on various collaborative processes, including long-term management of the Poudre River. Mark has a bachelor's degree from the University of Connecticut and master's degree from Johns Hopkins University.

David Merritt is a riparian plant ecologist with the National Watershed, Fish and Wildlife Program of the U.S. Forest Service in Fort Collins, Colorado. The main focus of his work is to understand the role of river flow regime in structuring plant communities and maintaining diversity in riparian areas; to characterize the influences of dams and diversions on riparian vegetation; and to understand the mechanisms associated with the invasion of riparian areas by non-native plant species. In his current position, David serves as a liaison between the research community and National Forest managers on water resource-related issues.

LeRoy Poff is a professor of biology and director of the graduate degree program in ecology at Colorado State University. He teaches courses in aquatic ecology, trains and mentors graduate students, and conducts externally funded research on aquatic and riparian ecosystems in diverse settings that include Colorado, Australia, and Ecuador. Since receiving his PhD in 1989, his research has specialized on the ecological consequences of how natural and human-caused hydrologic variability regulates the interactions among species and the structure and function of riverine ecosystems. His work has contributed directly to the development of the science of environmental flows, which aims to support sustainable management of streams and rivers – at local to regional to global scales – in the face of competing water demands. He has more than 100 peer-reviewed publications and is named a Highly Cited Researcher. He was elected president of the Society of Freshwater Science in 2007, and is a fellow in the Aldo Leopold Leadership Program of the Ecological Society of America.

John Sanderson, Director of Conservation Science for The Nature Conservancy (TNC) of Colorado, manages a staff of scientists and project directors to deliver conservation outcomes on a wide range of topics. These include ensuring adequate streamflow for endangered fish in the Yampa River, making energy development compatible with sage grouse on protected lands in northern Colorado, and keeping hundreds of thousands of acres on the Great Plains intact to support native wildlife. John holds a bachelor's degree in engineering from Purdue University, a master's degree in botany from the University of Vermont, and a PhD in ecology from Colorado State University.

Jennifer Shanahan is an environmental planner for the City of Fort Collins, Natural Areas Department. Jen participates in a variety of planning processes related to management of the city's 42 natural areas. Her position focuses on a spectrum of issues surrounding the Poudre River that include landscape-level planning, application of science to policy and management, technical communications between numerous projects, and communication of technical topics to the broader community. She holds a master's degree from the Department of Forest Rangeland and Watershed Stewardship at Colorado State University, with a research focus in riparian restoration.

John Stokes began his career more than 20 years ago with the Appalachian Trail Conference, a non-profit organization that oversees management and conservation of the Appalachian National Scenic Trail. John accepted a position with The Nature Conservancy (TNC) of Texas in 1993 and moved to Fort Collins in 1996 to work with TNC in Colorado. He left in 2003 as the director of TNC's eastern Colorado programs. John then became Director of Natural Resources for the City of Fort Collins, in charge of operations for environmental services and natural areas programs. In 2012, John transitioned to become the director of the currently named Natural Areas Department and serves in a new role as the City's point person on Poudre River issues. John holds a master's degree in urban and environmental planning from the University of Virginia.

APPENDIX B: TECHNICAL BASIS OF MODEL COMPONENTS

Appendices B1–B2 Contributed By:

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APPENDIX B1: CHANNEL STRUCTURE

METHODS

As an extension of the work presented in Section II of this report, this section further develops the technical basis for the development of the CMFI computations and thresholds associated with the Channel Structure indicator. First, the grain-size distributions used in the analysis will be discussed. Next, the three primary lines of evidence which helped inform the geomorphic/physical habitat components of the ERM will be examined in more detail, namely:

1) Dimensionless shear stress analyses that quantify the frequency and duration of flows that perform sediment flushing, river bed rejuvenation, and channel maintenance,
2) Effective discharge analysis of cumulative sediment transport capacity over the full spectrum of streamflows under historical conditions, and
3) Historical analysis of aerial images of the river planform and evidence of lateral migration.

Grain-size Distributions

The site-specific, grain-size distributions of the bed material used in the analyses were taken from a report by Ayres Associates (2001) and their sampling locations are provided in Table B.1 and Figure B.1, respectively. Not every site number had a sample that was deemed representative by Ayres Associates; therefore, surface gradations were based on their Wolman pebble counts and estimated substrate gradations on their grab sample gradation statistics. To define surface gradation in ERM Reach 3a, a representative sample of the upper portion of Ayres Reach 5 were used. Substrate gradation in this reach is based off a sample in Ayres Reach 4. The average of two samples closer to the end of Ayres Reach 5 is used for surface conditions in the ERM Reach 3b. For this reach, no single appropriate substrate sample exists, so samples from Ayres Reaches 4, 7, and 8 were averaged. The ERM Reach 7 uses a sample from Ayres Reach 15 for both the surface and substrate. The resulting values were similar to values estimated by CSU engineering students during laboratory exercises and recent CSU data collected as part of the post-2012 fire monitoring of the Poudre River (Daniel Baker, 2013, pers. comm.). These grain-size distributions were used for both the shear stress and effective discharge analyses. Pebble counts can tend to overestimate grain sizes because of measurement bias toward coarser particles (Bunte and Abt, 2001) but there are ways to decrease this bias (e.g. sampling frames).

Table B1.1. Sediment gradations (mm) used in the shear stress and effective discharge analyses.

	D5	D16	D35	D50	D65	D84	D95
Reach 3a							
Surface	16.0	30.8	43.2	52.6	63.9	84.7	110
Substrate	0.764	3.75	31.5	47.6	65.3	76.6	79.2
Reach 3b							
Surface	26.9	40.8	58.5	72.2	89.9	109	130
Substrate	0.554	2.85	18.8	29.4	50.3	63.2	70.8
Reach 7							
Surface	5.6	25.3	46.1	54.3	63.9	81.9	94.3
Substrate	1.38	5.63	29.8	50.3	54.9	62.9	77.7

Source: Ayres Associates, 2001.

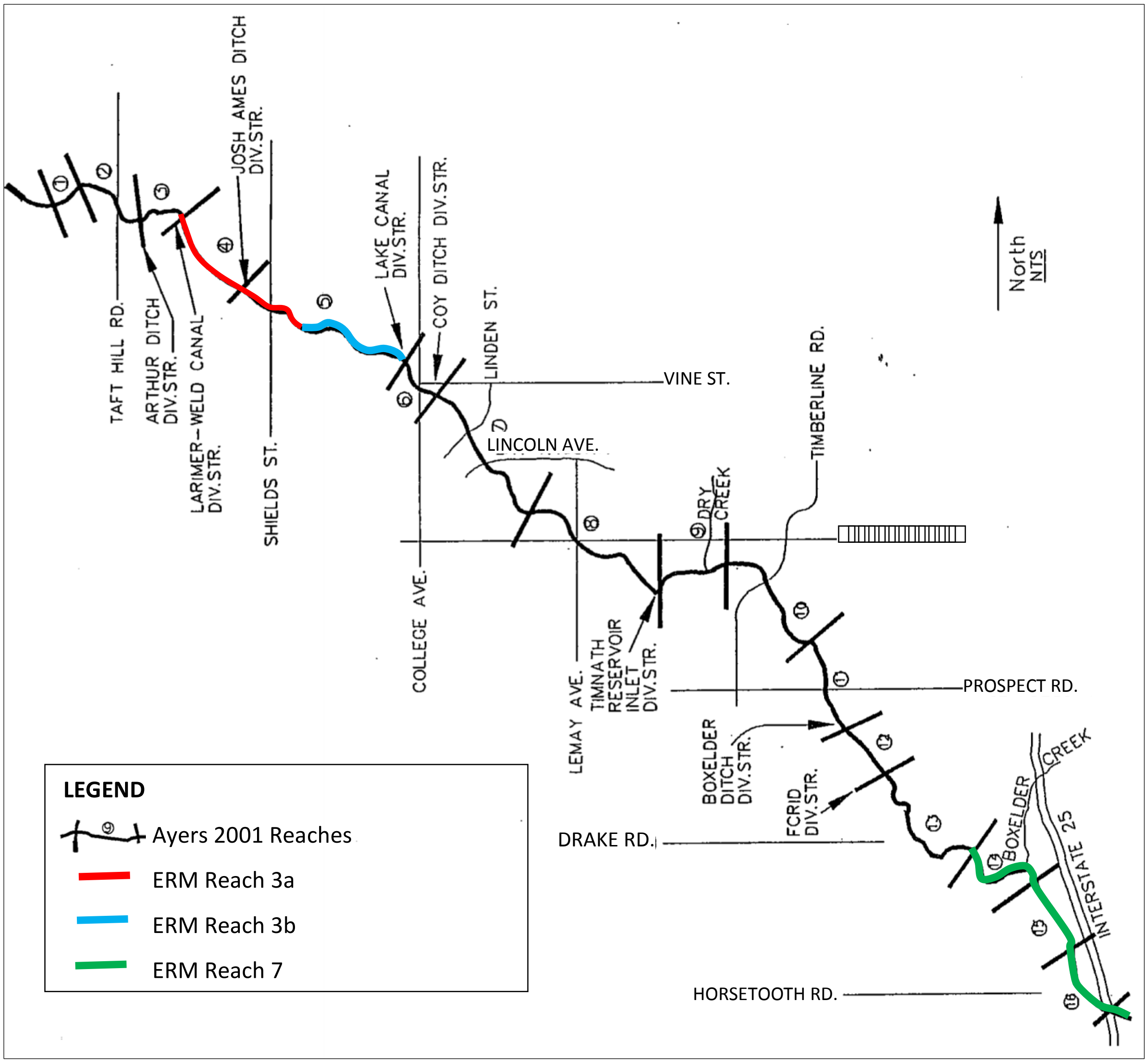

Figure B1.1: Sediment sample locations, in which red, blue and green lines indicate Reach 3a, Reach 3b, and Reach 7, respectively (adapted from Ayres, 2001).

Dimensionless Shear Stress Analysis

Dimensionless shear stress (τ_*) is a fundamental hydraulic parameter representing a ratio of erosive forces to resisting forces. It is commonly used in river mechanics to characterize the mobility of various sizes of sediment particles on the river bed. Dimensionless shear stress is defined as:

$$\tau_* = \frac{RS}{(G-1)d}$$

where *R* is hydraulic radius, *S* is slope, *G* is specific gravity of sediment (estimated at 2.65), and *d* represents grain diameter.

Most of the parameters needed to quantify shear stress at representative locations along the river corridor were generated using HEC-RAS 4.1 (USACE, 2010). The HEC-RAS model used in these analyses was provided by Anderson Consulting (Brad Anderson, 2011, pers. comm.; USACE, 2008), using cross sections measured by King Surveyors in 2007 as well as additional cross sections added by Anderson Consulting using other means (i.e., interpolation, repeated cross-sections, and photogrammetry). The model domain extends from the mouth of the canyon west of Fort Collins downstream past Greeley near the confluence with the South Platte River. A Manning *n* value of 0.035 used in the original model was maintained for the channel bed throughout Fort Collins. The HEC-RAS model already contained values for Manning *n* in overbank and impervious regions as approximately 0.05 and 0.025 with variation along the channel. These values were also retained. With these geometric inputs and a downstream boundary condition, HEC-RAS can calculate a water-surface profile, along with other corresponding parameters, for any given discharge. For this analysis, the downstream boundary condition was set as normal depth for a slope of 0.0036, which is the average bed-slope in the lower portion of the model domain. It is also important to note that model domain is much larger than the scale of this project; thus, the reaches in question are not sensitive to the selection of the downstream boundary condition.

Fifty-three different discharge values were modeled, ranging from 50 cfs up to 9,000 cfs using HEC-RAS, examining how main-channel shear stress, hydraulic radius of the channel, hydraulic depth of the channel, friction slope, and energy slope varied with streamflow. Although energy slope and friction slope are typically synonymous descriptions of the slope of the energy grade line in open channel flow, HEC-RAS provides different values because energy slope is estimated at a single cross-section, whereas friction slope is averaged over two cross-sections. Five different methods of calculating in-channel shear stress (τ) were compared (γ = specific weight of water):

1. main channel shear as calculated by the 1D HEC-RAS hydraulic model,
2. as estimated by $\tau = \gamma D S_e$, where *D* = hydraulic depth and S_e = energy slope
3. as estimated by $\tau = \gamma R S_e$, where *R* = hydraulic radius and S_e = energy slope
4. as estimated by $\tau = \gamma D S_f$, where *D* = hydraulic depth and S_f = friction slope
5. as estimated by $\tau = \gamma R S_f$, where *R* = hydraulic radius and S_f = friction slope

Visual inspection (see Figure B.2) of rating relationships indicated that using the product of hydraulic radius *R* and friction slope S_f provided the most physically realistic results in terms of how shear stress varies with discharge. Then, piecewise at-a-station hydraulic geometry relationships for shear stress, hydraulic radius, and friction slope as functions of discharge were developed. An example of a characteristic set of piecewise functions is shown in Figure B.3. After running the steady flow analyses, cross sections that were in close proximity to structures (such as weirs and bridges) and heavily influenced by backwater effects were removed from the HEC-RAS output before averaging reach-wide hydraulic characteristics. There is significant variation in these parameters among cross sections due to both inherent variability in channel forms and floodplain encroachment.

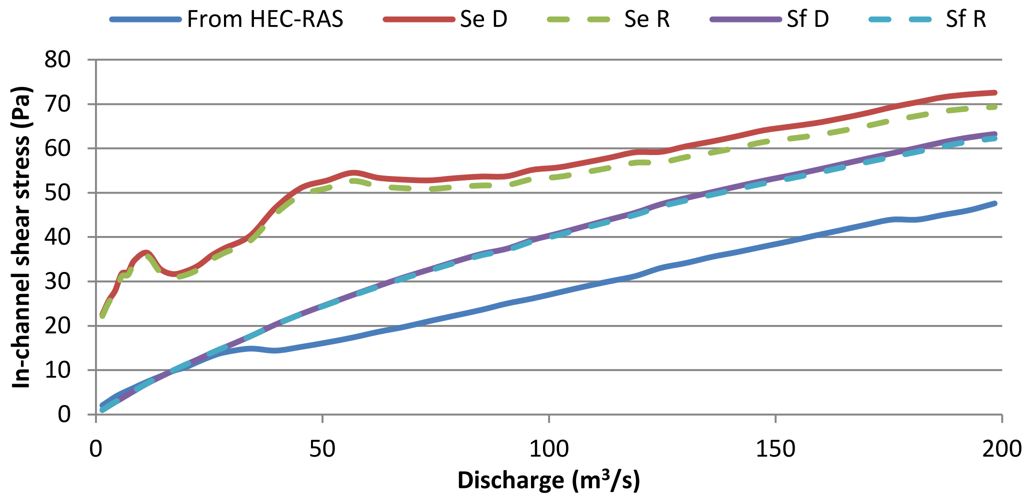

Figure B1.2: Reach-averaged relationships between shear stress and discharge in Reach 3a using various combinations of energy slope, friction slope, hydraulic radius, and depth.

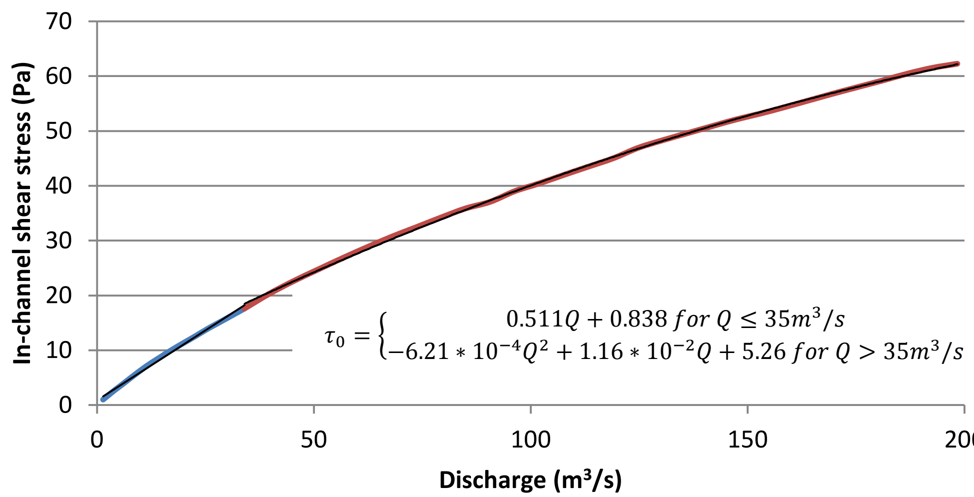

Figure B1.3. Piecewise at-a-station hydraulic geometry relationships between shear stress and discharge in Reach 3a.

Thresholds of dimensionless shear stress referenced to the median grain size of the river surface (D50) are associated with important geomorphic and ecological processes (e.g., ASCE, 1992; Milhous, 2000, 2003). These processes include the following.

- Algae scour/disturbance
- Sand/fine sediment flushing
- Limiting encroaching vegetation
- Armor breakup/full transport of bedload

Sediment movement in low gradient gravel-bed rivers can be described in terms of five general states (Table B.2).

Table B1.2: Interpretation of dimensionless shear stress values in terms of states of fine sediment flushing and coarse substrate mobilization.

	Dimensionless shear stress (τ_*) referenced to d_{50}	
Sediment movement state	**Lower bound**	**Upper bound**
Fines and sand are stored		0.009
Fines and sand in motion	0.009	0.021
Surface cleaning and removal of fines	0.021	0.035
Initial movement of armor and substrate cleaning	0.035	0.06
General movement of and cleaning of substrate	0.06–0.084	–

Source: Adapted from Milhous, 2000, 2003.

For the dimensionless shear stress analysis, spreadsheet tools were developed to quantify the frequency and average number of days per year that hydraulic conditions exceed incremental values of dimensionless shear stress (0.021, 0.030, 0.035, 0.040, 0.047, 0.053, and 0.060) referenced to estimated median grain size (D50) for any input streamflow series. These increments of dimensionless shear stress span varying degrees of river bed cleaning starting with removal of surficial deposits of fine sediments (0.021), to both surface cleaning and partial substrate cleaning (0.035), through increasingly thorough general cleaning of the substrate (0.040-0.06).

Results – Dimensionless Shear Stress Analysis

Using the main channel hydraulic radii and friction slopes from HEC-RAS (USACE, 2008; Brad Anderson, 2011, pers. comm.) in conjunction with site-specific grain-size distributions, estimates of discharges were calculated that correspond to ecologically-relevant thresholds of dimensionless shear stress for each reach (Table B.5).

Table B1.3: Discharge (cfs) corresponding to four thresholds of dimensionless shear stress at the three study locations.

Location	τ_* = 0.021	τ_* = 0.03	τ_* = 0.035	τ_* = 0.06
Reach 3a: Taft to Shields	1,750	2,700	3,300	6,900
Reach 3b: Shields to College Ave	1,400	2,500	3,200	8,000
Reach 7: Boxelder Gage to I-25	900	1,550	2,100	9,200

It is important to note that these values approximate the lower bound of the ranges in Table B.5 for flushing and substrate mobilization, and could potentially underestimate the flows required to perform these geomorphic functions. In general, substrate flushing and mobilization is a patchy and dynamic phenomenon; thus, conceptualizing substrate flushing and mobilization as a sort of on/off switch is erroneous. For example, a dimensionless shear stress of 0.03, based on cross-section averaged hydraulic characteristics, results in patches of the river bed that range from little or no transport to those experiencing intense transport with τ_* exceeding 0.06 in many cross sections. Values of critical dimensionless shear stress (referenced to D50) in the range of 0.01 to 0.03 are commonly observed in low-gradient, gravel-bed rivers like the Poudre (Buffington and Montgomery, 1997; Ferguson, 2012). This reflects the fact the cross-section averaged hydraulic characteristics tend to bias the actual shear stress and transport downward in irregular sections with zones of greater depth that produce nonlinear increases in transport.

Effective Discharge Analyses

For several decades, geomorphologists and engineers have recognized the value of coupling continuous flow series with sediment-transport relationships to quantify the combined effects of flow and sediment regime using Magnitude-Frequency Analysis (MFA) (Wolman and Miller, 1960). In this approach, the estimated geomorphic "effectiveness" (i.e., long-term sediment-transport capacity) of different flow levels is multiplied by the likelihood of occurrence (Pickup and Warner, 1976; Andrews, 1980; Emmett and Wolman, 2001). The flow with the largest product of sediment transport capacity and frequency is deemed the "effective discharge." For gravel bed snowmelt rivers like the Poudre, the effective discharge generally corresponds to range of flows that is most influential in performing geomorphic work and maintaining the channel over a period of years (Andrews, 1980; Emmett and Wolman, 2001).

In practical applications of MFA, discharge values are typically arranged into a specified number of discrete classes, referred to henceforth as "bins." The number of observations in each bin represents a flow frequency relative to the total number of flows recorded. The product of the sediment-transport capacity of a representative flow from each bin and its flow frequency produces an estimate of how much sediment can be transported by each bin. This procedure results in a series of discrete product values that form an effectiveness curve, with the highest point in an effectiveness curve representing an estimate of the effective discharge, the flow that transports the largest portion of the annual sediment yield the period of record (Andrews, 1980). The area under the effectiveness curve represents the time-integrated capacity to transport sediment through the channel.

Effective discharge analyses were performed using methods recommended by the USACE (Biedenharn et al., 2000; Soar and Thorne, 2001) to develop a second line of evidence for quantifying channel maintenance flows in the ERM. Twenty-five arithmetic flow bins and two bedload functions that bracket the hydraulic conditions and substrate characteristics of the Poudre River were used: 1) the Parker *et al*. (1982) bedload equation, and 2) the Wilcock and Crowe (2003) bedload equations. A description of these sediment-transport relationships follows.

Parker et al. (1982) Surface-based Relation

The bedload relation of Parker *et al*. (1982) is widely used in analyses of gravel-bed rivers. It is based solely on field data, mostly from Oak Creek, Oregon but also several other streams. The shear stresses were computed from depth-slope products, and it was assumed that drag at gravel-transporting flows was negligible:

For $\phi_i > 1.65$ $$q_{bv_i} = f_i g^{1/2}(G-1)^{-1}\left[11.2\left(1-\frac{0.822}{\phi_i}\right)^{4.5}\right](RS)^{3/2}$$

For $0.95 \le \phi_i \le 1.65$ $$q_{bv_i} = f_i g^{1/2}(G-1)^{-1}[0.0025\exp[14.2(\phi_i-1)-9.28(\phi_i-1)^2]](RS)^{3/2}$$

$$\phi_i = \frac{\tau_{*_i}}{\tau_{*_{ri}}}$$

Where ϕ_i is the ratio of dimensionless shear stress to reference dimensionless shear for a particular grain size class; *g* is acceleration due to gravity; *G* is specific gravity of sediment estimated at 2.65; and f_i

is a number between 0 and 1, representing the fraction of sediments in grain-size class *i*. Dimensionless shear stress for a given size class is defined as:

$$\tau_{*_i} = \frac{RS}{1.65 d_i}$$

Where d_i is geometric average grain diameter of fraction *i*. The volumetric bedload transport per time per channel width for a given bed-material size fraction is represented by q_{bvi}. The q_{bvi} for each size fraction are summed and multiplied by the channel width available for transport to calculate the sediment-transport capacity. Characteristic transport widths of 24.4 m, 21.3 m, and 12.2 m were used for the Reaches 3a, 3b, and 7, respectively. The Parker (1990) transport relation was also used for ϕ < 0.95 following Wilcock *et al*. (2009) and the U. S. Forest Service BAGS software package.

In the absence of a relationship calibrated at the specific site of interest, the following surface relationship developed by Andrews and Nankervis (1995) using field data from the Poudre River near Rustic, Colorado, provides a reasonable estimate of reference shear stress:

$$\tau_{ri}^{*} = 0.035(d_i/d_{50})^{-0.942}$$

Andrews (1984) also provided a reference dimensionless shear stress equation based on subsurface data from the East Fork River in Wyoming, and the Snake and Clear Water Rivers in Idaho:

$$\tau_{ci}^{*} = 0.0834(d_i/d_{u50})^{-0.872}$$

Wilcock and Crowe (2003)

The Wilcock and Crowe (2003) equation defines reference dimensionless shear stress as a function of sand content. The hiding function is taken to be a function of grain size *i* and the median grain size:

$$\tau_{r50}^{*} = 0.021 \pm .015\exp[-20F_s]$$

Where F_s is the fraction of sand on the bed surface:

$$\frac{\tau_{ri}^{*}}{\tau_{r50}^{*}} = \left(\frac{d_i}{d_{50}}\right)^{b}, \qquad b = \frac{0.67}{1 + \exp\left(1.5 - \frac{d_i}{d_{50}}\right)}$$

$$W_i^{*} = \frac{(G-1)gq_{bvi}}{f_i\left({}^{\tau}/_{\rho}\right)^{3/2}} = \begin{cases} 0.002\phi^{7.5} & for\ \phi < 1.35 \\ 14\left(1 - \frac{0.894}{\phi^{0.5}}\right)^{4.5} & for\ \phi \geq 1.35 \end{cases}$$

Where W_i* is the dimensionless transport rate of size fraction *i* and τ is shear stress (in Pa).

Flow Records – Effective Discharge

The effective discharge analyses were based on the Recent Past flow scenario (water years 1970-2010) (see Section II for more details[1]) representing flow conditions at the Lincoln Street in Fort Collins (USGS gage 06752260) with flow adjusted through the city based on operations of diversions and additions (Donnie Dustin, 2011, pers. comm.; Andy Pineda, 2011, pers. comm.) The Poudre River is primarily a

[1] Note that USGS gage 06752260 began operations in April 1975. Data prior to that date is based upon the point-flow model further described in Table II.3 of the ERM Report

snowmelt-driven river, thus the rate of the change of flows is low, and use of daily average flows (as compared to 15 minute flows) provides acceptable results (Biedenharn *et al*., 2000). The differences between peak annual stream flow and corresponding daily average for the last 13 years in the record, as provided by the USGS gage 06752260, are presented in Table B.3. This indicates that daily average peak flow values provide a reasonably good representation of sub-daily flow peaks.

Table B1.4: Difference in peak and daily average flow conditions 1983-1995.

Date	Peak flow (cfs)	Daily average flow (cfs)	Difference (%)
6/21/1983	6674	6080	10%
5/25/1984	3426	2890	18%
6/9/1985	2260	1870	21%
6/7/1986	3426	3020	14%
6/9/1987	883	316	182%
6/11/1988	1236	933	33%
5/30/1989	706	492	46%
6/9/1990	1801	1190	51%
6/2/1991	3270	2430	39%
6/24/1992	953	429	124%
6/19/1993	2684	2470	9%
6/1/1994	1377	937	48%
6/18/1995	3500	3500	0%
Total average			46%
Average of flows above 2472 m^3/s			15%

In 1983, the Poudre River watershed experienced an extreme snowpack that provided not only the highest daily maximum (in the 1970-2010 period) of 6080 cfs, but also 28 of the top 30 daily average flows for the recent past flow record and the top 16 daily average flows for the native flow record. Peak stream flow for the 1983 event has a 19-year return interval based on the 37-year (1975–2011) peak annual stream flow record provided by the USGS at the Lincoln Street gage (Table B.4). More importantly, this event had an extremely long duration, and as a result, is very influential in determining the frequency distribution of high flows. Average stream flow for 1983 was 779 cfs, which is 490% higher than the average annual stream flow in the same 37-year period (1975–2011), 88% higher than the second highest year (1980 at 413 cfs), and is even higher than the peak stream flow of 1989. Due to these factors, the top 35 flow days from the 1983 water year were dropped to reduce the skew introduced to the effective discharge curves provided by a large number of high-flow days in 1983 and to determine the geomorphic effectiveness of flows other than the extreme 1983 event. This resulted in a 39% reduction(6074 to 3708 cfs) in the largest daily-averaged flow in the record of calculation, November 1, 1969–October 31, 2010, for the Recent Past scenario. The average annual discharge was reduced down to the level of most of the other high-flow years (from 777 to 346 cfs), which would make it the fourth highest annual average flow year in the 38-year record.

Table B1.5: Return interval analysis of instantaneous peak flows at the USGS Lincoln Street gage.

Flow (cfs)	Return interval
4767	10
3355	5
2649	2.5
1413	1.5
≈706	1

Sensitivity Analyses – Effective Discharge

For the effective discharge computations, two types of sensitivity analyses were performed by varying: 1) reference shear stress relationships, and 2) the number of flow bins used to discretize the flow records (following Biedenharn *et al*., 2000).

The substrate of the Poudre River through Fort Collins is armored in many locations and this generally reduces the sediment transport and increases the effective discharge. To better understand the magnitude of change in effective discharge if the armor layer was mobilized, substrate gradations were also used, as well as proportions of the surface gradation, in the surface relation of Parker *et al*. (1982). In addition, it was estimated the effective discharge were estimated based on the Andrews (1984) substrate equation, substrate gradation for Parker surface composite, substrate gradation for Parker substrate equation, as well as 2.5% and 5% surface sand in the Wilcock and Crowe (2003) equation.

Sensitivity to the number of flow bins used in the analysis was also examined. Using the effective discharge estimated with the entire flow distribution, the range of flows were narrowed incrementally to investigate how the effective discharge would change. Particular interest was given to the smallest bin size that avoided zero frequencies following Biedenharn *et al*., (2000).

Results – Effective Discharge Analysis

Ranges of effective discharges for each of these methods and for each reach are provided In Table B.6. The effective discharge values, based on the Parker surface composite method, closely match (within 2–8%) the discharge corresponding to a dimensionless shear stress value of 0.035 in each of the three river segments and are insensitive to the binning method and modest changes in reference shear stress and substrate characteristics. The convergence of results from the dimensionless shear stress analyses and the various effective discharge computations indicate that the discharges selected for substrate rejuvenation/channel maintenance are reasonable estimates until more detailed, site-specific monitoring can be performed.

Table B1.6: Effective discharge values (in cfs) under all methods for current conditions.

	Parker *et al*. surface composite		Parker *et al*. subsurface equation			Wilcock and Crowe		
	Gradation		Andrews modification	Gradation		Percent sand		
	Surface	Substrate		Surface	Substrate	0%	2.5%	5%
Reach 3a	3350	3350	3350	3350	3350	2120	2120	2120
Reach 3b	3350	3350	3350	3350	3350	2470	2120	2120
Reach 7	2650	2650	3710	3710	3710	2650	2650	2650

Although variations in reference shear method examined do not change the value of effective discharge values, they do produce a large variation in the amount of sediment transported at all ranges of discharges as is typical when utilizing diverse sediment-transport relations. The Parker surface composite, under both gradations, is always equal to the mode of estimated discharge values. For Reach 3a, removal of the top flows of 1983 reduces the range of flows by 39%; however, there is a consistent local maximum in all graphs around 3350 cfs. Results of the analysis of sensitivity to the number of flow bins are provided in Table B.7.

Table B1.7: Effective discharge by bin size for the current flow record using Parker surface composite.

Bin Size (cfs)	Effective discharge (cfs)		
	Reach 3a	Reach 3b	Reach 7
39	3320	3320	2966
49	3320	3567	2966
60	3602	3320	3002
71	3355	3355	3002
81	3320	3320	2613
92	3284	3284	3002
99	3320	3320	3002
109	3284	3284	2966
120	3284	3284	3037
Median	3320	3320	3002

Historical Analysis of Aerial Images

To explore historical changes in river planform and identify flow magnitudes associated with channel migration and creation of potential recruitment areas for plains cottonwood, maps and aerial imagery was examined from several time periods. Data sources included a detailed survey of Fort Collins from 1874 and available aerial photographs from 1937, 1984, 1999, 2002, and 2005. USGS historic photographs were also examined (though most were of poor quality) as well as images available through Google Earth, which has 11 sets of photographs from October 3, 1999–October 27, 2011. The time series of aerial photographs were examined in the context of the flow record at the USGS gage on the Poudre River at Lincoln Street (1975–2010) in an effort to estimate or bracket the magnitude of flows that have resulted in channel migration or areas of the river corridor that have partial or no lateral armoring.

Results – Historical Analysis of Aerial Images

The Poudre has experienced considerable channel migration from 1874 to the present, but most of this migration occurred before 1972. The exact mechanisms of planform adjustment are uncertain, though it appears that many of the significant changes were the result of direct human manipulation of the channel. The 1937 aerials provide the first high-quality images, and there is evidence of active channel migration due to natural processes at that time; however, with the exception of somewhat isolated changes in 1999, subsequent adjustments in channel planform depicted in the available photographs correlate directly to changes in human land uses along the corridor.

The ERM team was not able to locate suitable pre- and post-1983 imagery to assess the effects of the large and extended duration runoff event in that year. Therefore, the response to the 1999 high-flow event was primarily used to make inferences about the flow magnitudes that are associated with the type of channel adjustments and scour needed to maintain channel complexity for habitat and support recruitment of plains cottonwood in the riparian corridor. The flashy high flow of April 30, 1999 is somewhat anomalous in that it was generated by a rain on snow event that resulted in an instantaneous peak flow of 7,700 cfs, a value 2,000 cfs higher than the average daily flow of 5,640 cfs. In contrast to the long-duration 1983 event, the 1999 event exceeded 4,000 cfs for only three days. Despite its relatively short duration, the flow in April 1999 provided substantial scouring of point bars, newly-deposited lateral bars, and lateral migration in several locations with relatively low amounts of bank armoring (e.g., segment downstream of Shields Avenue). An additional short-duration, high-intensity flooding event occurred in September 2013. This rainfall-driven event peaked near 8,000 cfs, yet was only above 4,000 cfs for two days. The 2013 event created newly deposited lateral bars and caused minor lateral migration, but failed to mobilize vegetation on point bars last scoured in the 1999 event. In contrast to the 1999 event, a 2010 event with instantaneous and daily averaged peaks of 4,570 and 3,700 cfs, respectively, induced little detectable change in terms of bar formation or channel migration. Accordingly, it appears that daily averaged flows in the vicinity of 5,000 to 6,000 cfs may be required to produce substantial bar formation and scouring in locations lacking effective bank armoring. Depending on location, such flows would correspond to a τ_* exceeding 0.06 (referenced to D50 of the channel substrate).

As described above, it appears that occasional flows exceeding 5,000 to 6,000 cfs are necessary to induce channel adjustments that support plains cottonwood recruitment and maintenance of habitat complexity (e.g., pool-riffle sequences). However, such adjustments are only likely to occur in locations with minimal lateral armoring, or armoring that is set back from the channel banks. In many locations along the river, it is difficult to discern the extent of armoring because mature vegetation has developed on top of riprap that was emplaced decades ago. To better understand the extent of lateral armoring throughout the urban corridor, city staff compiled a map of lateral armoring and riprapped locations as described in the Riparian Methods in Section II. The map reveals that there are relatively few locations along the river that lack substantial armoring; this indicates that it is necessary to account for lateral armoring in the ERM to mediate the potential for high flows to induce channel adjustments that would create new habitats and opportunities for recruitment of plains cottonwood.

Extensive armoring is not unexpected in locations with infrastructure and human encroachment into the floodplain; however, there are a few segments along the urban corridor where natural river migration would not threaten human safety and infrastructure. These segments are the focus of the channel migration/habitat diversity flow analysis in that they could represent potential safe locations for cottonwood recruitment with reduced or setback armoring.

Initial Probability Development for Channel Structure

Building upon the above analyses, our initial probability construct attempted to bring together dimensionless shear stress exceedance with duration and frequency in a single table (Table B.8).

Table B1.8: Probabilities of three states of sediment flushing and bed mobilization based on dimensionless shear stress values, frequency of occurrence, and duration within a year.

Surface flushing	**Clean and diverse**[2]	**Marginally mobile**[3]	**Entrenched**[4]
τ_* exceeds 0.021 for 5+ days in 3 of 4 years	0.8	0.2	0
τ_* exceeds 0.021 for 3+ days in 2 of 3 years	0.4	0.5	0.1
τ_* exceeds 0.021 for 2+ days in 1 of 2 years	0	0.4	0.6
less than above	0	0	1
Bed mobilization / substrate rejuvenation			
τ_* exceeds 0.035 for 3+ days in 1 of 2 years	0.8	0.2	0
τ_* exceeds 0.035 for 3+ days in 1 of 3 years	0.5	0.4	0.1
τ_* exceeds 0.03 for 3+ days in 1 of 2 years	0.3	0.5	0.2
τ_* exceeds 0.03 for 1+ days in 1 of 3 years	0	0.3	0.7
less than above	0	0	1

NOTE: The information in this table was not directly used in the final model, but was used to inform the development of the CMFI metric

The primary challenge we faced when using these discretized shear thresholds was that they were not sensitive to differences among scenarios. For example, two flow scenarios that generate τ_* of 0.022 and 0.029 would be placed in the same probability bin, despite the fact that one has substantially greater potential to mobilize bed material. We therefore resolved to create a continuous variable which factored in both the magnitude and duration of shear stress exceedance events – the channel maintenance flow index (CMFI).

[2] Substrate clean on surface, interstitial space open, vegetation encroachment not advancing, channel has wide variety of depth, velocity, substrate combinations with morphologically diverse features such as side channels, chutes, bars owing to substantial removal of lateral bank stabilization.
[3] Flushing occurs at least every few years, interstitial space open in high-stress zones such as riffles, vegetation encroachment slowly advancing in low-stress zones, habitat diversity flows may be intact but bank stabilization partially limiting channel complexity.
[4] Partial to no substrate cleaning, channel maintenance absent, interstitial space not opened > 3–5 years, extensive bank stabilization, canal-like homogeneous channel.

CMFI development

Building off all the previous analyses we created a magnitude and duration metric, called the channel maintenance flow index (CMFI). The CMFI provides a continuous metric of channel maintenance effectiveness based on excess shear stress and its duration; therefore, it avoids issues associated with discretization approaches based on categorical thresholds of shear stress that are relatively insensitive to differences among similar scenarios. The CMFI equation is:

$$CMFI = \sum_{i=1,n} \left(\frac{\tau_{*i}}{\tau_{*R}}\right)^{1.5} \left(\frac{D}{D_c}\right)$$

Wherein:

τ_*	=	dimensionless shear stress
τ_{*R}	=	dimensionless reference shear stress capable of initiating geomorphic processes of interest
D	=	duration (days)
D_c	=	duration ceiling above which no additional geomorphic benefit is calculated
n	=	number of days during a year of record in which $\tau_{*R}$is exceeded

The CMFI metric essentially integrates how intensely, long, and often flushing occurs into a single continuous score for each flow scenario. This metric combines an excess shear ratio (non-linearized by raising the ratio to the 1.5 power after Wong and Parker (2006) and others) with a duration ratio. Two separate CMFI scores are computed; one for flushing (CMFI-F) and another for bed mobilization (CMFI-M) using the reference shear and duration ceiling values found in Table B1.9. Yearly CMFI scores were then averaged by summing the CMFI values across all years and dividing by the years in the analysis period.

Table B1.9: Summary of the reference shear (τ_{*R}) and duration ceiling (D_c) for the computation of CMFI-F (fine sediment flushing) and CMFI-M (coarse substrate mobilization).

Function	τ_{*R}	D_c
Fine sediment flushing (CMFI-F)	0.021	5
Bed mobility (CMFI-M)	0.030	5

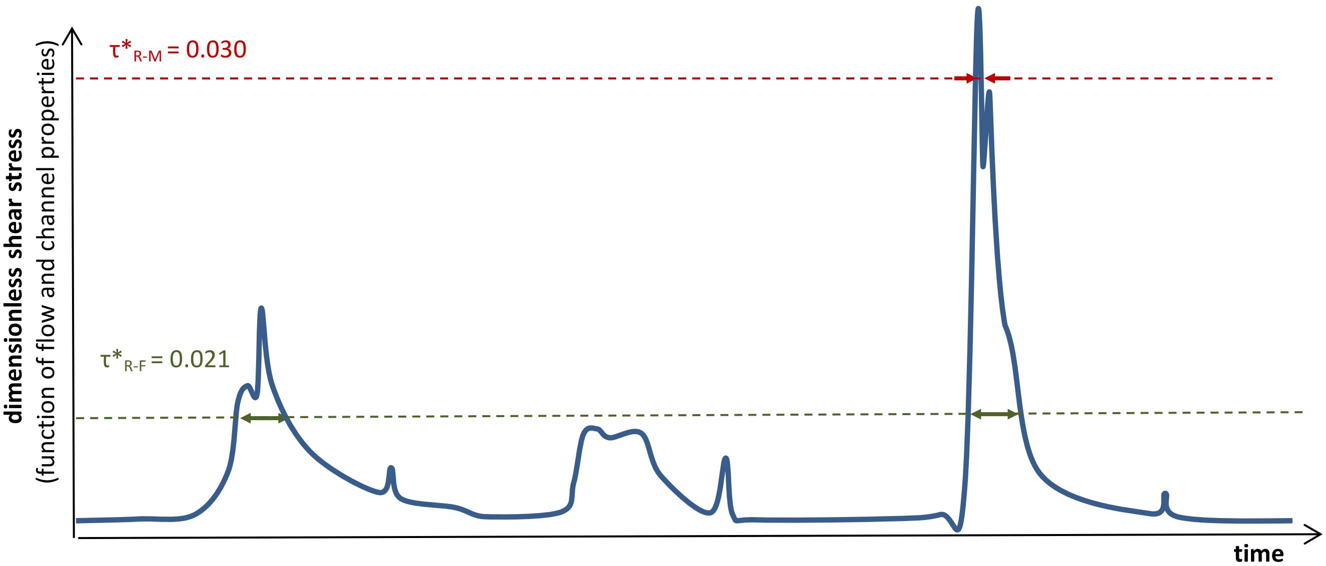

Figure B1.4: Visual explanation of the influences of magnitude, duration, frequency on Channel Structure over a hypothetical three year period.

Note:

Magnitude (height over thresholds): *The channel maintenance flow index (CMFI) computation is dependent on flow levels increasing the dimensionless shear stress (τ*) of the channel above a critical dimensionless shear stress of $\tau^*_{R\text{-}F}$ = 0.021 for fine sediment flushing and $\tau^*_{R\text{-}M}$ = 0.030 for bed mobility. The higher the flow, the higher the CMFI value, as indicated by the ratio of the actual τ* to the reference raised to the 1.5 power.*

Duration (time over thresholds): *The duration of shear stress above the critical value is a secondary contributor to the overall effectiveness of peak flows to improve channel structure. The CMFI equation demonstrates a linear scale to this duration term with a 5 day cap. Thus, 2 days of flow over the critical value gives you just 2/5 of the benefit of 5 days. Greater than 5 days does not improve the benefit over the 5 day cap.*

Frequency (fraction of years over thresholds): *Frequency enters the computations in the transition of CMFI values to the final Channel Structure probabilities. The more often flushing or mobility events occur, the more they will positively influence Channel structure. Flushing is desired 2 out of 3 years and bed mobility 1 out of 3 years (matching the frequencies of this figure).*

The end product is a physically-based and intuitive equation for quantifying flows associated with sedimentation processes such as surface flushing of fine sediments and coarse substrate mobilization. Convergence of results from previous analyses (shear and Qeff) informed thresholds used in the CMFI approach.

The analysis steps to convert the CMFI values to their final distributions were as follows.

A. Determine controlling process (flushing fines or bed mobilization). As flow rate increases, the channel maintenance functions transition from a state of no maintenance, gradually into surface flushing only, and finally to full flushing and substrate mobility. Using Table B1.8 as a basis, we found flushing to be fully engaged at a value of CMFI-F = 1.0 (τ_* = 0.021 for 5 days). Again using Table B1.8 as a basis, we found the lower limit of bed mobility at a CMFI-M = 0.34 (τ_* = 0.03 for 1 day). Comparing CMFI-F and CMFI-M values across flow scenarios, it was found that this pair of values coincided with each other. Thus, scenarios with CMFI-F ≤ 1.0 are deemed to only involve flushing of surficial deposits of fine sediment. For CMFI-F > 1.0 (and hence CMFI-

M > approx. 0.34), shear stresses transition into the flushing plus bed mobility range and CMFI-M is used.

B. Normalize CMFI values. As the goal of the Channel Maintenance analysis was a single probability distribution for each flow scenario based its intensity, duration, and frequency of both flushing and substrate cleaning, it was then necessary to collapse the CMFI-F and CMFI-M variables into a single linear function. As indicated above, CMFI-F = 1.0 and CMFI-M = 0.34 coincided, thus we used those values as a cross-over point in creating an index function with a minimum value of 0 and a maximum of 1 (Figure B1.4).

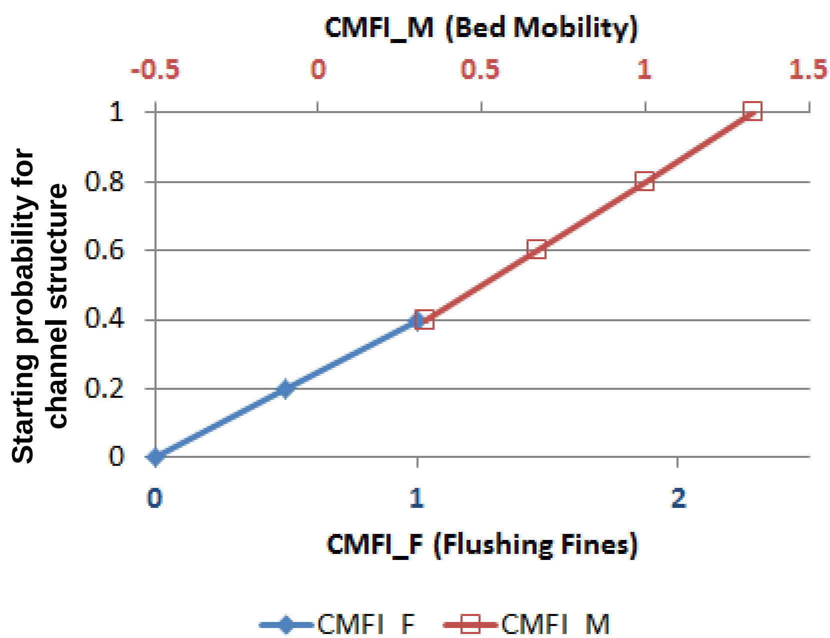

Figure B1.5: This figure demonstrates which process (flushing fines or bed mobility) controls the computation of the starting value for developing channel structure probabilities.

Note: It also assigns a value function to the continuous values of CMFI_F and CMFI_M. Note the equivalence of CMFI_F= 1.0 and CMFI_M = 0.34 (Step B above)

C. Assign uncertainty. It was then assumed that the uncertainty of the resulting normalized starting value was 25% of its original value (analogous to a coefficient of variation equal to 0.25). This uncertainty could be adjusted in future iterations of the model, given more in-depth information.

D. Adjust for frequency. If the fine sediment flushing and bed mobility occur less frequently, the resulting channel condition will likely degrade and the uncertainty about that condition is likely to increase. The inverse is also true; higher frequency equates to improved condition and less uncertainty. Thus the channel condition probability was adjusted linearly, using the following benchmarks (Table B 1.10). Benchmarks and channel states were established by eliciting expert judgment from Peter Wilcock (Johns Hopkins University) and Robert Milhous (USGS Retired), as well as from review of literature from similar systems, and return intervals were informed by ecological and sediment transport theory.

Table B1.10: Summary table of adjustment factors for flushing and bed mobility frequency intervals

Level	Flushing return interval (yrs)	Bed mobility return interval (yrs)	Multiplier for mean probability	Multiplier for standard deviation of probability
Minimum*	1.3	2.0	1.2	0.7
Mean	1.5	3.0	1	1
Maximum**	5.0	7.0	0.3	2

*Return intervals less than the minimum were held to the multipliers for the minimum level
*if the return intervals were greater than the Max value, then the mean probability was set to zero and the standard deviation multiplied by 3.

E. Limit by bank stabilization (armoring). Bank stabilization was then able to limit the mean channel condition according to the following rules:

Table B1.11: Bank stabilization category definitions and adjustments to mean channel condition

Bank stability category	Definition	Adjustment to mean channel condition
Minimal	Stabilized length occurring at any distance from channel center line is < 5% of bank length.	None
Altered	Stabilized length > 5% of bank length and stabilized length occurring < 50 m from channel center line is < 15% of bank length.	Limit state probability to 0.875
Protected	Stabilized length occurring < 50 m from channel center line is 15– 30% of bank length.	Limit state probability to 0.75
Stabilized	Stabilized length occurring < 50 m from channel center line is > 30% of bank length.	Limit state probability to 0.625

F. Compute distribution and bin. Lastly, the final weighted mean and standard deviation were used to develop a normal curve for the probability of channel condition for each flow scenario. The probabilities were then binned into the states in Table II.4.

Table B1.12: Description of four states of Channel Structure that depend on the combined status of flushing flows, coarse substrate mobilization, channel migration flows, and extent of armoring.

Likely State	Channel Condition Values	Description
Clean and diverse	0.75-1.00	Flushing and bed mobility flow functions intact, substrate clean on surface, interstitial space open, vegetation encroachment not advancing, channel has wide variety of depth, velocity, substrate combinations with morphologically diverse features such as side channels, chutes, bars owing to substantial removal of lateral armoring.
Partially mobile and diverse	0.50-0.75	All three flow functions at least partially intact, flushing occurs at least every few years, interstitial space open in high-stress zones such as riffles, vegetation encroachment slowly advancing in low-stress zones, habitat diversity flows may be intact but lateral armoring partially limiting channel complexity.

Largely immobile and homogeneous	0.25-0.50	Bed mobilization and/or channel migration flows not intact, flushing partially or not intact, vegetation encroachment likely advancing, river increasingly canal-like with homogeneous habitat until partially reset by an extreme event that overcomes riprap armoring in isolated locations, substrate flushing at least partially intact, habitat diversity flows could be intact but lateral armor present.
Entrenched	0.00-0.25	Partial to no substrate cleaning, channel maintenance absent, interstitial space not opened > 3–5 years, extensive lateral armoring, canal-like homogeneous channel.

The CMFI was applied to the full period of record for all flow scenarios.

APPENDIX B2: ALGAE AND NUTRIENTS

The following graphs summarize the exceedance probability of likely nutrient concentrations over the six hydrologic scenarios (see Figures B.4 through B.7). They can be interpreted as the percent of the time flows (y-axis) will likely have nutrient concentrations of a given value (x-axis). Also displayed on the graphs as vertical red-dashed lines are estimated threshold values for increased levels of algae growth; in the case of nitrogen this is around 0.4 mg/L (Dodds *et al*., 1997, 2002) and for phosphorus 0.11 (proposed cold-water standard for total phosphorus from Elmund *et al*. (2011)). As a demonstration of how you could read these graphs:

> Q: What is the fraction of time the total nitrogen concentration at Lincoln Street (Figure B.4) is above the threshold during the reconstructed natural scenario?
>
> A: By observing that the reconstructed native flow scenario crosses the 0.4-mg/L threshold at around 10%, one can deduce that the nutrient concentrations of the natural flow scenario are estimated to be above the threshold 10% of the time.

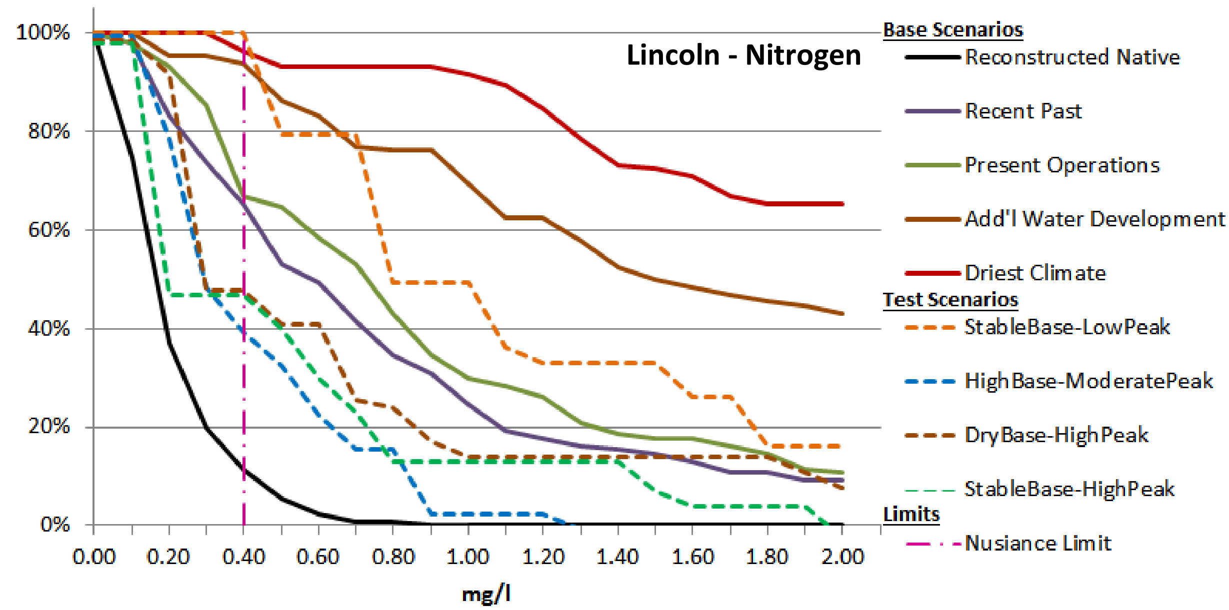

Figure B2.1: Exceedance probabilities of Base Scenarios and Test Scenarios for total nitrogen at Lincoln Street estimated for the period of record WYs 1970–1995 across multiple hydrologic scenarios.

Note: Also shows the 0.4-mg/L threshold for nuisance growth of algae (Dodds et al., 1997, 2002).

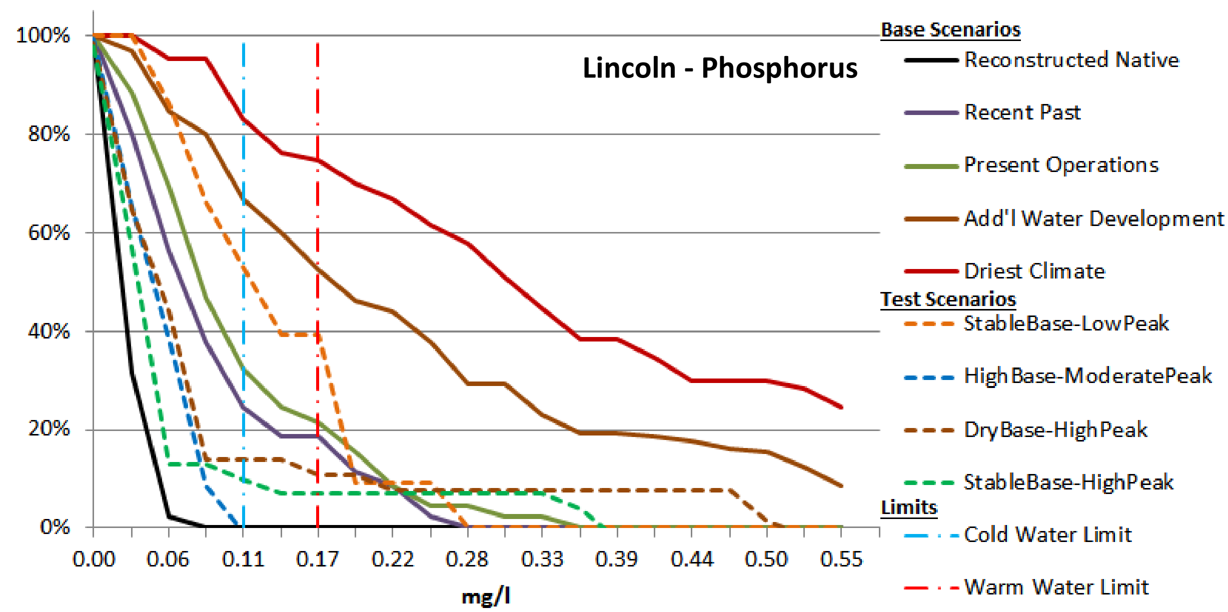

Figure B2.2: Exceedance probabilities of Base Scenarios and Test Scenarios for total phosphorus at Lincoln Street estimated for the period of record WYs 1970–1995 across multiple hydrologic scenarios.

Note: As a point of reference related to the nuisance growth of algae, the graph also displays the proposed median annual limits for both cold and warm water (Lincoln will be classified as a warm water reach as of March 2013), which can only be exceeded one in five years (Elmund et al., 2011).

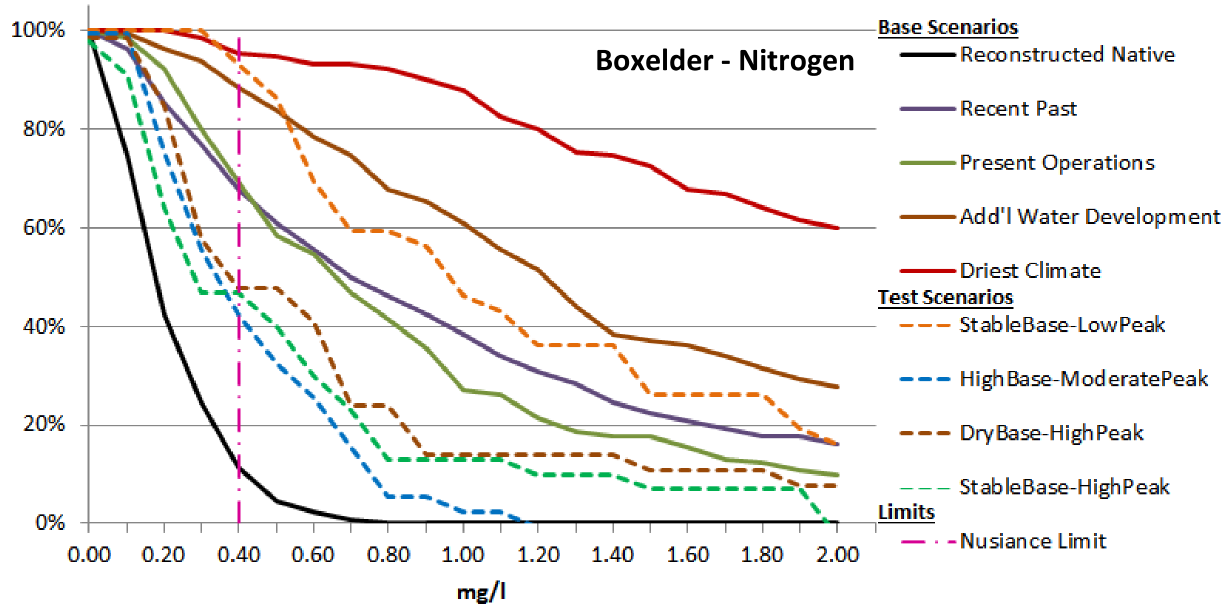

Figure B2.3: Exceedance probabilities of Base Scenarios and Test Scenarios for total nitrogen at Boxelder Creek estimated for the period of record WYs 1970–1995 across multiple hydrologic scenarios.

Note: Also shows the 0.4-mg/L threshold for nuisance growth of algae (Dodds et al., 1997, 2002).

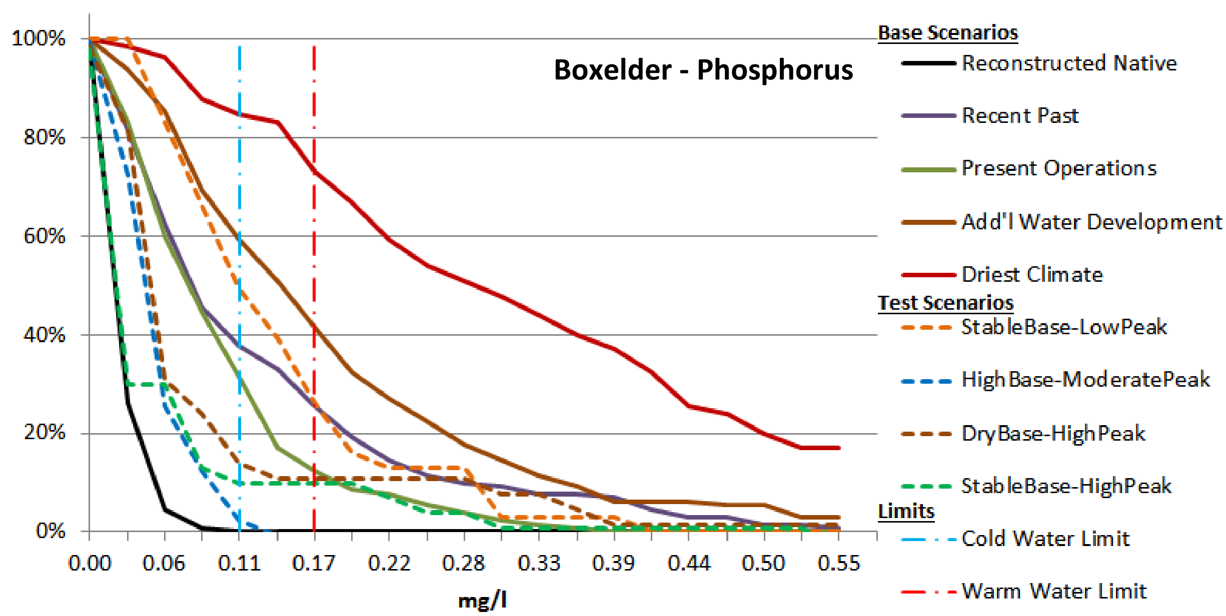

Figure B2.4: Exceedance probabilities of Base Scenarios and Test Scenarios for total phosphorus at Boxelder estimated for the period of record WYs 1970–1995 across multiple hydrologic scenarios.

Note: As a point of reference related to the nuisance growth of algae, the graph also displays the proposed median annual limits for both cold and warm water (Boxelder will be classified as a warm water reach as of March 2013), which can only be exceeded one in five years (Elmund et al., 2011; CDPHE, 2012).

Table B2.1: Probabilities for the impacts of nutrient enrichment and scouring flows on Algae.

Total nitrogen (NO3+NO2+TKN) – relative enrichment as compared to Recent Past scenario	Dissolved phosphorus (PO_4) – relative enrichment as compared to Recent Past scenario	Algae-flushing flow function	Probabilities for Algae: Less than today	About the same as today	More than today
Significant improvement	Significant improvement	Intact	0.9	0.1	0
Significant improvement	Significant improvement	Partially intact	0.6	0.3	0.1
Significant improvement	Significant improvement	Absent	0.4	0.4	0.2
Significant improvement	About the same	Intact	0.7	0.2	0.1
Significant improvement	About the same	Partially intact	0.4	0.4	0.2
Significant improvement	About the same	Absent	0.2	0.5	0.3
Significant improvement	Significant enrichment	Intact	0.5	0.4	0.1
Significant improvement	Significant enrichment	Partially intact	0.3	0.4	0.3
Significant improvement	Significant enrichment	Absent	0.1	0.4	0.5
About the same	Significant improvement	Intact	0.7	0.2	0.1
About the same	Significant improvement	Partially intact	0.4	0.4	0.2
About the same	Significant improvement	Absent	0.2	0.5	0.3
About the same	About the same	Intact	0.5	0.4	0.1
About the same	About the same	Partially intact	0.3	0.4	0.3
About the same	About the same	Absent	0.1	0.4	0.5
About the same	Significant enrichment	Intact	0.3	0.4	0.3
About the same	Significant enrichment	Partially intact	0.2	0.3	0.5
About the same	Significant enrichment	Absent	0	0.2	0.8
Significant enrichment	Significant improvement	Intact	0.5	0.4	0.1
Significant enrichment	Significant improvement	Partially intact	0.3	0.4	0.3
Significant enrichment	Significant improvement	Absent	0.1	0.4	0.5
Significant enrichment	About the same	Intact	0.3	0.4	0.3
Significant enrichment	About the same	Partially intact	0.2	0.3	0.5
Significant enrichment	About the same	Absent	0	0.2	0.8
Significant enrichment	Significant enrichment	Intact	0.1	0.2	0.7
Significant enrichment	Significant enrichment	Partially intact	0	0.2	0.8
Significant enrichment	Significant enrichment	Absent	0	0	1

APPENDIX B3: AQUATIC INSECTS

Table B3.1is a master list of taxa used in the ERM and their designation as sensitive taxa (EPT). This list is a compilation of data from Grotheer *et al*. (1994), Shieh *et al*. (1999, 2002), Voelz *et al*. (2000, 2005), USGS (2003), and Rice and Bestgen (2006).

Table B3.1: A master list for the taxa of Aquatic Insects.

TAXA	EPT (y/n)	TAXA	EPT (y/n)	TAXA	EPT (y/n)
Acentrella	y	Eukiefferiella		OLIGOCHAETA	
Agraylea	y	Euparyphus		Ophiogomphus s	
Amphiagrion		Fallceon quilleri	y	Optioservus	
Antocha		Ferrissia		Orthocladius	
Arctopsyche grandis	y	Glossosoma	y	Palpomyia	
Asellus		Glyptotendipes		Parachironomus	
Atherix		Gyraulus		Paraleptophlebia	y
Baetis	y	Helicopsyche borealis	y	Pentaneura	
Berosus		Hemerodromia		Pericoma	
Brachycentrus	y	Heptagenia	y	Petrophila	
Brillia		Hesperoperla pacifica	y	Phaenopsectra	
Caenis	y	Heterlimnius corpulentus		Physella	
Capnia	y	Hexagenia limbata	y	Pisidium	
Cardiocladius		Hexatoma		Polypedilum	
Chelifera		Hyalella		Procladius	
Cheumatopsyche	y	HYDRACARINA		Psectrocladius	
Chironomus		Hydropsyche	y	Pseudochironomus	
Cinygmula	y	Hydroptila	y	Psychomyia flavida	y
Claassenia subulosa	y	Isoperla	y	Rhithrogena	y
Clinocera		Isotomurus		Rhyacophila	y
Corynoneura		Kiefferulus		Serratella micheneri	y
Crangonyx		Lepidostoma	y	Simulium	
Cricotopus		Leptophlebia cupida	y	Skwala americana	y
Cryptochironomus		Limnophora		Stictochironomus	
Cultus aestivalis	y	Lopescladius		Sweltsa	y
Diamesa		Lymnaea		Tanypus	
Dicranota		Mesovelia		Tanytarsus	
Diplocladius		Microtendipes		Thienemanniella	
Drunella	y	Microvelia		Tipula	
Dugesia		Narpus concolor		Trichocorixa	
Endochironomus		Nectopsyche	y	Tricorythodes	y
Epeorus	y	Ecdyonurus	y	Triznaka signata	y
Ephemerella	y	NEMATODA		Zaitzevia parvula	
Erpobdella		Oecetis	y	Zapada	y

APPENDIX B4: BROWN TROUT AND NATIVE FISH

Background

The Poudre River originates in high-elevation mountains of the Front Range near Cameron Pass about 68 km west of Fort Collins, Colorado. The stream flows in a mostly easterly direction downstream to the foothills area. In high-elevation areas (> 1,900 m above sea level), the Poudre River is primarily a high-velocity, cold, high-gradient, and rocky-bottomed stream. Few fish species in the region are adapted to cold-water temperatures, so high-elevation mountain streams support primarily cold-water fishes such as trout. As the Poudre River emerges from the foothills, the character of the river changes to one that meanders more broadly, and water velocity is slower in wider, lower gradient valley reaches of this transition zone (approximately 1,600 to 1,900 m altitude; Propst (1982)). The fish community of a typical transition reach in the South Platte River Basin of Colorado includes brown trout (*Salmo trutta*), suckers (*Catostomus* sp.), and various minnows such as longnose dace (*Rhinichthys cataractae*). Stream substrate is still predominantly rocky, but water temperatures warm as the river passes through the transition zone. Associated with these physical habitat changes is a concurrent change in the fish community to species that tolerate cool (not cold) water temperature regimes. The transition zone continues downstream from the foothills to the vicinity of Fort Collins. The portion of the river that supports cool-water salmonids shifts downstream during years of higher and colder flows (e.g., since about 2008), such that brown trout may be relatively common as far downstream as Prospect Bridge. In warmer years, distribution of brown trout may be restricted mainly to the reach upstream of College Avenue.

Downstream from Fort Collins, the Poudre River enters the plains reach. In its natural (non-channelized) state, it meandered broadly across a wider floodplain, had relatively low gradient and current velocity, and probably had substrate composed of smaller particles such as sand and small gravel. Water temperatures in the plains reach are warmer than those in the transition zone and the Poudre River supports fish communities that are composed primarily of minnows, suckers, and darters; trout have been documented downstream into some plains reaches, but that likely occurred only in years with higher cooler flows.

The primary study area of concern in this report was the Poudre River from just west of College Avenue, Fort Collins, downstream to the ELC near the eastern terminus of Horsetooth Avenue. This section of the Poudre River is mostly in the transition zone and supports a mixture of cool- and warm-water fishes.

Study Sites

Inference was drawn to fish data gathered at two main sites in the study area. The first site is just upstream of College Avenue and adjacent the McMurray Natural Area and just upstream of Martinez Park (Site #1 in Bestgen and Fausch,1993). Collections at this site were initiated in 1990 and extended through 2006, with the exception of 1997 when no sampling occurred. After 2006, sampling was moved downstream to a site just upstream of the Lincoln Street Bridge; some inferences will be made to those data as well. The river at this site meanders slightly within channelized banks, but generally retains some of its natural character because some stream banks that have intact riparian trees are undercut but stable. Channelization, levees, and bank stabilization (e.g. riprap) at this site prevent the river from eroding into adjacent gravel-pit ponds, work which was apparently done prior to initiating collections. Habitat is diverse and consists primarily of deep runs and pools, and shallow riffles; substrate is predominantly cobble and gravel. The downstream half of the site is shaded by riparian trees that stabilize moderately undercut banks. Bank vegetation in the upstream half of the site consists of grasses and sedges, and small trees. Large woody debris created habitat instream for large-bodied fishes at various times during sampling but is often removed, which simplifies habitat and reduces holding cover for large-bodied fishes including trout and suckers. This river reach is isolated upstream and downstream by nearby diversion dams. Discharge was normally higher at this site than at others, presumably due to increased downstream diversion, but generally reflects the discharge patterns at the Lincoln Street USGS gage (#06752260).

The second site (ELC) (Site #3 in Bestgen and Fausch, 1993) is located between Fort Collins Wastewater Treatment Plant #2 and the Boxelder Sanitation District effluent discharges. Sampling began here in spring 1981, and the site has not been moved during the study period. The river meandered slightly in this reach within incised and channelized banks. Habitat was somewhat diverse and included deep pools, shallow riffles, and a backwater. Substrate in deep pools and backwaters was generally thick, anaerobic silt over cobble. Riffle substrate was cobble and gravel, but was usually embedded with fine sediments. Riparian vegetation in the form of large cottonwoods and other trees was abundant and banks were generally stable and grass covered. This site was adjacent to gravel-pit ponds on the north side and to the Fort Collins ELC on the south side of the channel. The river has been severely channelized and the left bank armored since about 2005, presumably for protection of infrastructure at Boxelder Sanitation District, which eliminated much of the deep pool habitat and instream cover in the form of large woody debris. Flows at this site are typical of those at the USGS gage above Boxelder Creek (#06752280), which is located at the upstream end of the study area.

Several locations were also sampled between the Mulberry and Prospect Street bridges from 1990 until present (e.g., Site #2 in Bestgen and Fausch,1993). Some inferences are made to the fish communities there as well when defining probability states related to various model-driving variables.

Fish Collections

Fish collections were made at the Poudre River mostly using bank-based electrofishing gear, though in some years fine-mesh seines were used to supplement sampling effort. The same locations were sampled each year so that consistency of habitat was ensured unless sites were permanently changed due to proximity of bridges, channelization, or other unavoidable factors. Sampling times at sites were standardized to 45 minutes. Although samples were available from a variety of seasons, late summer or autumn samples were mostly used to maintain consistency (especially to determine year-class strength of brown trout produced the winter before). Typically one to two passes through the site were made, depending on the complexity of the habitat and the number of fish caught. Two persons electrofished and netted fish while two to four additional people netted and transported fish. All fishes were then identified to species, counted, and weighed (all individuals of a species combined, except trout where individual lengths and weights were usually taken), and returned to the river. Habitat and river conditions and sampling efficiency were also recorded.

Overall, during low-flow conditions, electrofishing was thought to obtain a representative sample of the fishes of a given reach. Tests of sampling efficiency of electrofishing gear were conducted at one simple site (Site #7) and one moderately complex site due to habitat diversity (Site #10) in the Poudre River. During repeated electrofishing passes at both sites, all but one of the fish species eventually caught in four passes was caught on the first pass. In each case, the remaining species caught was represented by a single individual that was caught on the second pass. Since one to two passes were generally made at each site in the Poudre River, most species at the site were probably caught by this method. That same evaluation of electrofishing efficiency also indicated that nearly half of the fish eventually caught in four passes were caught in the first pass, so that a good representation of fish numbers was also achieved by this method.

APPENDIX B5: RIPARIAN VEGETATION

POUDRE RIVER RIPARIAN VEGETATION PROBABILISTIC MODELING

Objectives

The objective of modeling riparian vegetation as a function of present flow regime along the Poudre River was to develop the ability to predict probability of change in vegetation attributes as a function of possible future changes in river flow regime. Vegetation data provided by the City of Fort Collins (Shanahan, 2009) served as the basis for the vegetation component of this work. Hydraulic models and an interdiversion flow portioning algorithm were provided by Anderson Consulting Engineers, Inc. (ACOE, 2008; Brad Anderson, 2011, pers. comm.). Vegetation attributes of interest in this work included presence/absence of: 1) hydrophytic (wetland) vegetation, 2) *Salix exigua* (sandbar willow), 3) *Populus deltoides* (plains cottonwood), and 4) *P. deltoides* seedlings. Hydrophytic vegetation closely corresponds to the Riverine Wetlands indicator in the Bayesian model and the long-term presence of *S. exigua*, *P. deltoides*, and *P. deltoides* seedlings are associated with the Rejuvenating Mosaic indicator in the Bayesian model.

Methods

The City of Fort Collins provided an ArcGIS shapefile of vegetation transects along the Poudre River and a triangulated irregular network (TIN) of elevations (±1 m) for the study segment of interest. Vegetation plot (*N* = 194) locations were derived from field-measured distances along 55 transects. Many transects were short and the generally occupied only one side of the river. A point coverage was generated to include each vegetation plot. Vegetation data included presence-absence and cover of all woody species in the plots and hydrophytic herbaceous vegetation. Presence-absence of seedlings of woody species was also recorded. The elevation TIN was converted to raster format and used to extract elevations for the vegetation transect endpoints and the center points of vegetation plots.

An ArcGIS shapefile of channel cross-sectional data and a HEC-RAS hydraulic model of the Poudre River were obtained from ACOE. Flows were modeled on the Poudre River between the town of Laporte and Interstate-25. Discharge at which vegetation plots became inundated was calculated using rating curves developed from these hydraulic models. Water-surfaces were generated using a range of flows at each HEC-RAS transect. Inundating discharge for each vegetation plot was determined through iteratively increasing discharge modeled until plot center points were inundated. Water-surface elevation of vegetation transects at various flows was calculated by interpolating between the water surface elevations of the upstream and downstream HEC-RAS transects at the respective flows. Two vegetation plots at Cottonwood Hollow and 16 plots at the Environmental learning Center (Reach 6) were excluded due to insufficient hydraulic data at those sites.

Maps in raster format showing the area and probability of inundation were created in ArcGIS for the following flows: 200, 300, 400, 500, 600, 700, 800, 900, 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, 4,000, 4,500, 5,000, 5,500, 6,000, 6,500, and 7,000 cfs. The data to create these maps came from the HEC-RAS model and from exceedance probabilities of these flows occurring during the growing season (May–September). Exceedance probabilities were calculated from reconstructed flow data for seven inter-diversion reaches of the Poudre River. This output was also used to create the tables of inundated width (area divided by channel length) as a function of discharge used in riparian Bayesian network variables.

Grids of exceedance probabilities were initially created for the entire Poudre River between Laporte and Interstate-25, and were based on the width of the HEC-RAS transects. For final analysis, the area of interest was confined to the area inundated at a flow of 7,000 cfs. The river water surface at 200 cfs, water bodies adjacent to the stream, and hardened structures (e.g., buildings, roads, and parking lots) were clipped from the area of interest and excluded from modeling results.

To calibrate exceedance probability models, data from Poudre River diversions and inputs were used to calculate exceedance probabilities during the growing season for seven reaches between the town of Laporte and Interstate-25. Presence and absence of each of the riparian vegetation attributes of interest were modeled as a function of Recent Past (Section II) exceedance probabilities using realized niche modeling (Jongman *et al*., 1995; Guisan and Zimmermann, 2000). Logistic regression model fit and significance were determined using Hosmer-Lemeshow (HL) goodness of fit tests and -2 log likelihood (LL). When significant, models were then used to predict the probability of occurrence in each 1 m x 1 m grid cell of each of the four vegetation attributes in the entire area of interest in ArcGIS. Model predictions of measured values were evaluated using cross validation error rates.

To examine possible future climate conditions and water development actions, nine different flow scenarios were developed (Hydrologic Scenarios, Section II). Exceedance probabilities for these scenarios were calculated and grids of exceedance probabilities were generated. Raster probability maps were created for the entire Poudre River study area for each flow scenario using ArcGIS.

Results

The model for *hydrophytic (wetland) vegetation* was significant (LL $p < 0.0001$) and the goodness of fit test indicated that model fit to the data was excellent (HL $p = 0.28$,where values < 0.05 would indicate a significant lack of fit). Cross validation indicated that the model correctly predicted presence of observed hydrophytic vegetation 68% of the time. The model for *Salix exigua* (sandbar willow) was also significant (LL $p < 0.0001$) and the goodness of fit test indicated that model fit to the data was excellent (HL $p = 0.36$). Cross validation indicated that the model correctly predicted presence of hydrophytic vegetation 73% of the time.

Results for the *hydrophytic (wetland) vegetation* model are presented in Figures B5.1, B5.3, B5.4, B5.5, B5.6, B5.7, B5.9, and B5.15.

Results for the *Salix exigua* (sandbar willow) model are presented in Figures B5.1, B5.8, B5.10, B5.11, B5.12, B5.13, B5.14 and B5.16.

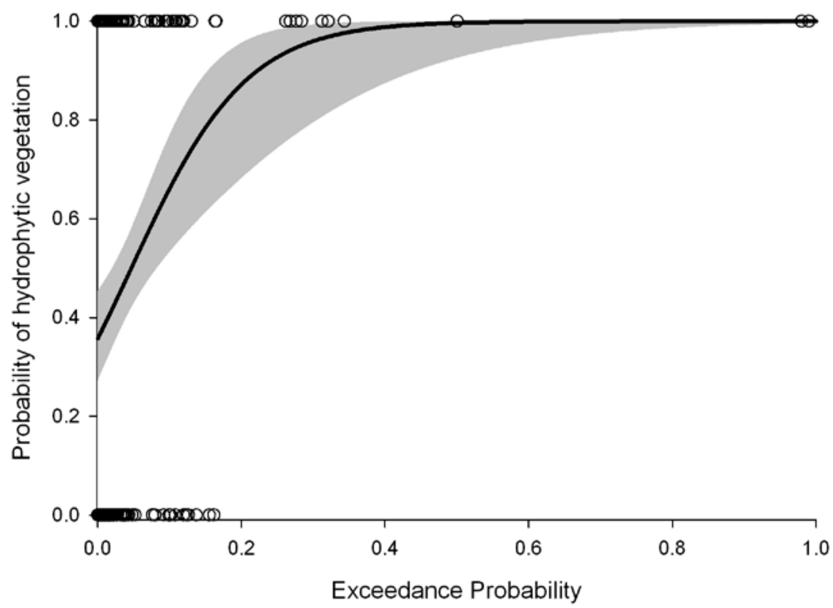

Figure B5.1: Probability of herbaceous hydrophytic (wetland) vegetation occurrence as a function of inundation.

Note: Exceedance probability is the fraction of the growing season that the vegetation plot is inundated (higher values are wetter). Circles are individual plots where presence=1 or absence=0. The model fit was significant (p < 0.0001) and predictions of measured data were 68% correct. The shaded zone is the 95% confidence interval.

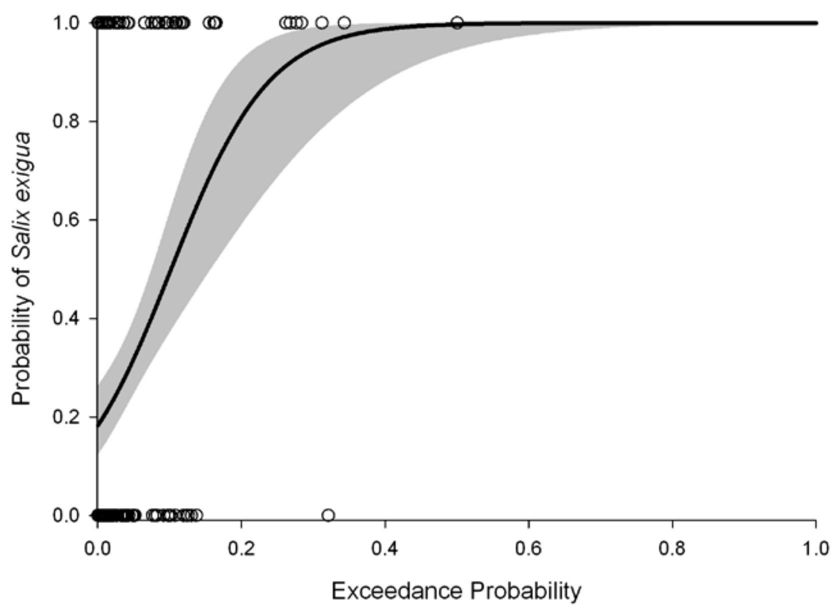

Figure B5.2: Probability of *Salix exigua* (sandbar willow) occurrence as a function of inundation.

Note: Exceedance probability is the fraction of the growing season that the vegetation plot is inundated (higher values are wetter). Circles are individual plots where presence=1 or absence=0. The model fit was significant (p < 0.0001) and predictions of measured data were 73 % correct. The shaded zone is the 95% confidence interval.

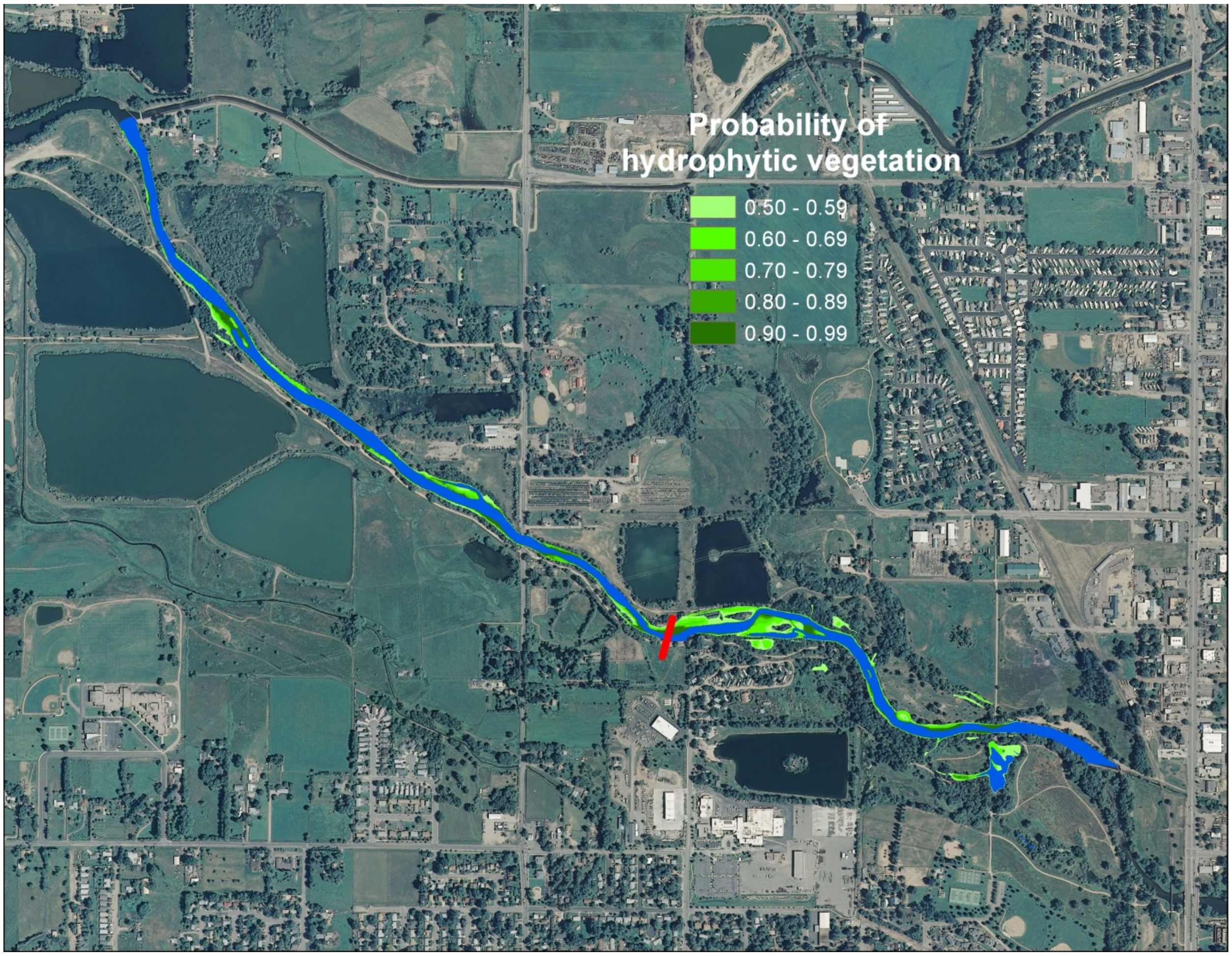

Figure B5.3: Probability of hydrophytic vegetation along Poudre River Reaches 3a and 3b as a function of exceedance probability for Recent Past flows.

Note: Reach 3a is to the left of the red line and Reach 3b is to the right. Along Reach 3a, 1.4 ha (7 m average width) of wetland vegetation is predicted under the Recent Past regime and 2.9 ha (23 m average width) is predicted for Reach 3b.

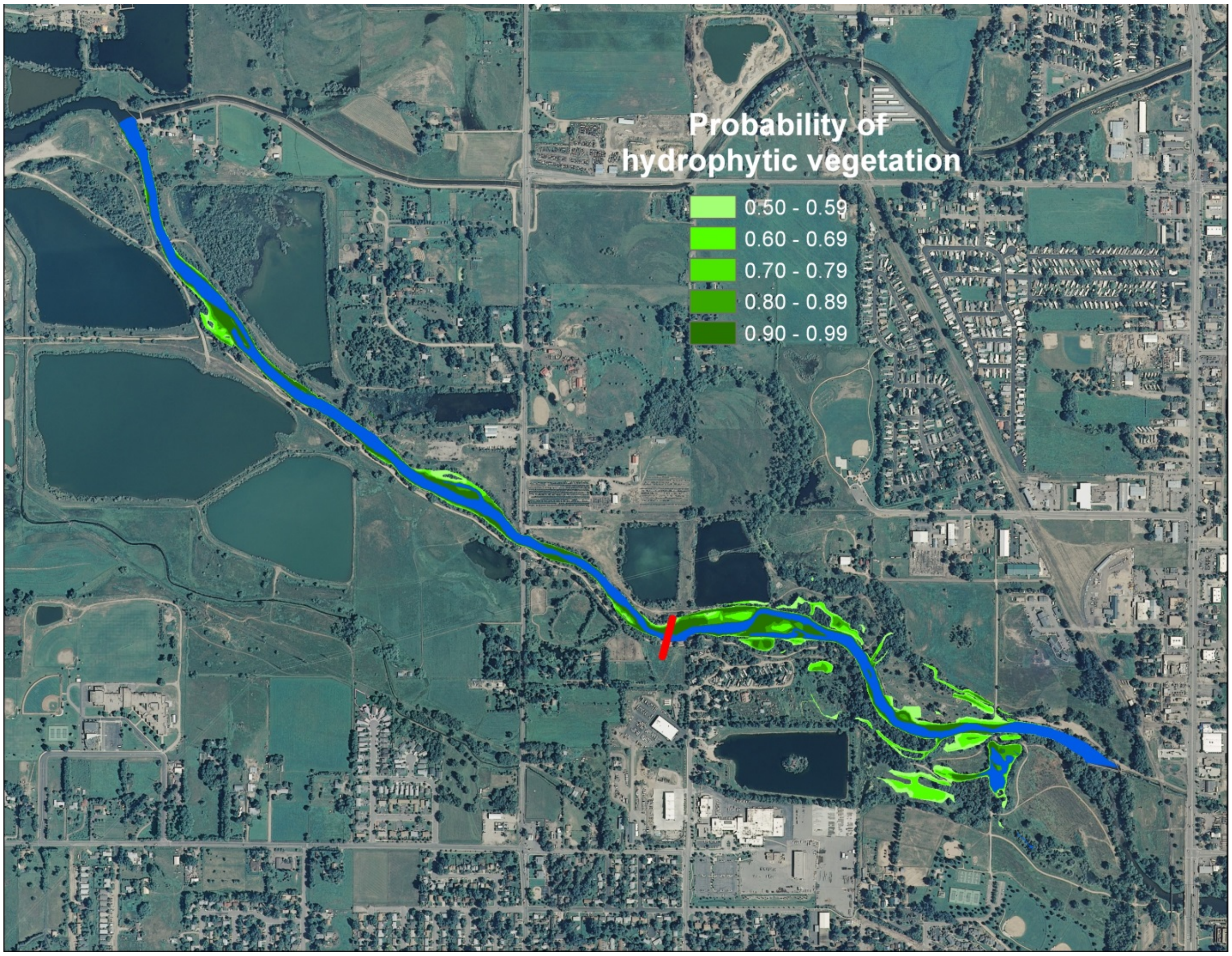

Figure B5.4: Probability of hydrophytic vegetation along Poudre River Reaches 3a and 3b as a function of exceedance probability for Reconstructed Native flows (reconstructed flow record without water diversions).

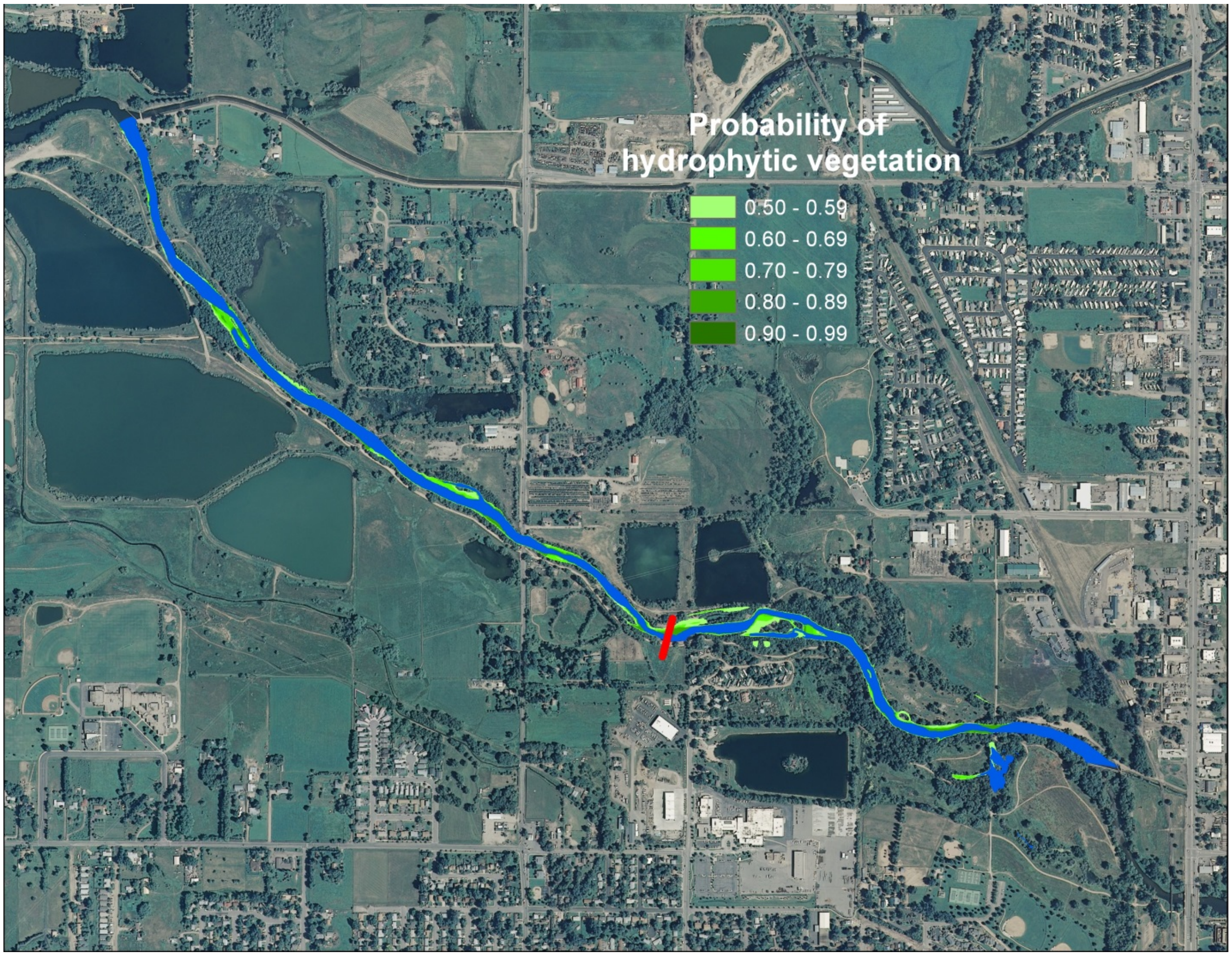

Figure B5.5: Probability of hydrophytic vegetation along Poudre River Reaches 3a and 3b as a function of exceedance probability for Present Operations continued flow scenario.

Note: Reach 3a is to the left of the red line and Reach 3b is to the right. Along Reach 3a, 0.8 ha (4 m average width) of wetland vegetation is predicted under the Recent Past regime and 1.5 ha (12 m average width) is predicted for Reach 3b.

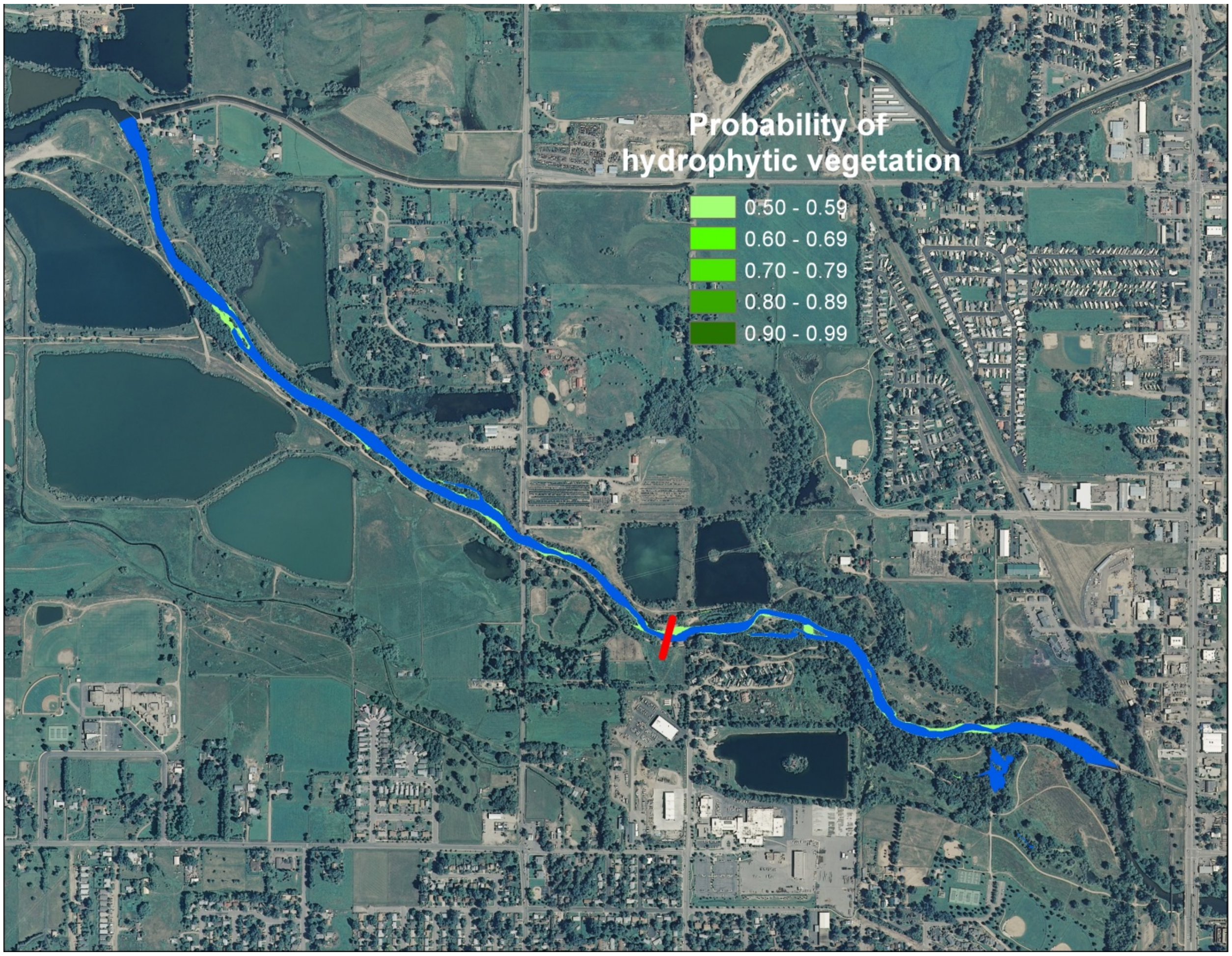

Figure B5.6: Probability of hydrophytic vegetation along Poudre River Reaches 3a and 3b as a function of exceedance probability for Additional Water Development flow scenario.

Note: Reach 3a is to the left of the red line and Reach 3b is to the right. No wetland vegetation was predicted (> 0.6 probability) along Reaches 3a or 3b under the Additional Water Development scenario. The light green areas all had probabilities ranging from 0.5–0.59.

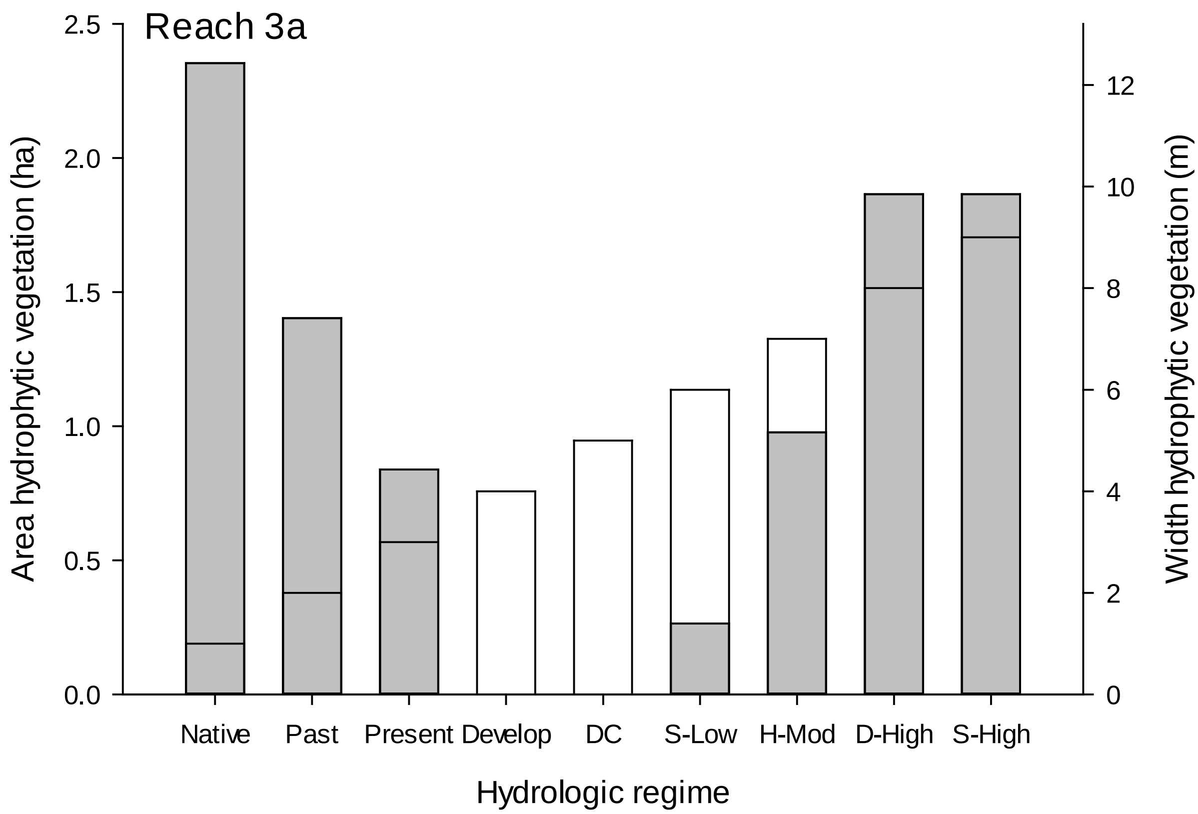

Figure B5.7: Predicted areal extent (in hectares) and average width (areal extent divided by reach length in meters) for hydrophytic vegetation in Reach 3a.

Note: Abbreviated scenario names represent: Reconstructed Native (Native), Recent Past (Past), Present Operations (Present), Additional Water Development (Develop), Driest Climate (DC), StableBase-LowPeak (S-Low), HighBase-ModeratePeak (H-Mod), DryBase-HighPeak (D-High), and StableBase-HighPeak (S-High) scenarios (refer to text for full descriptions of scenarios).

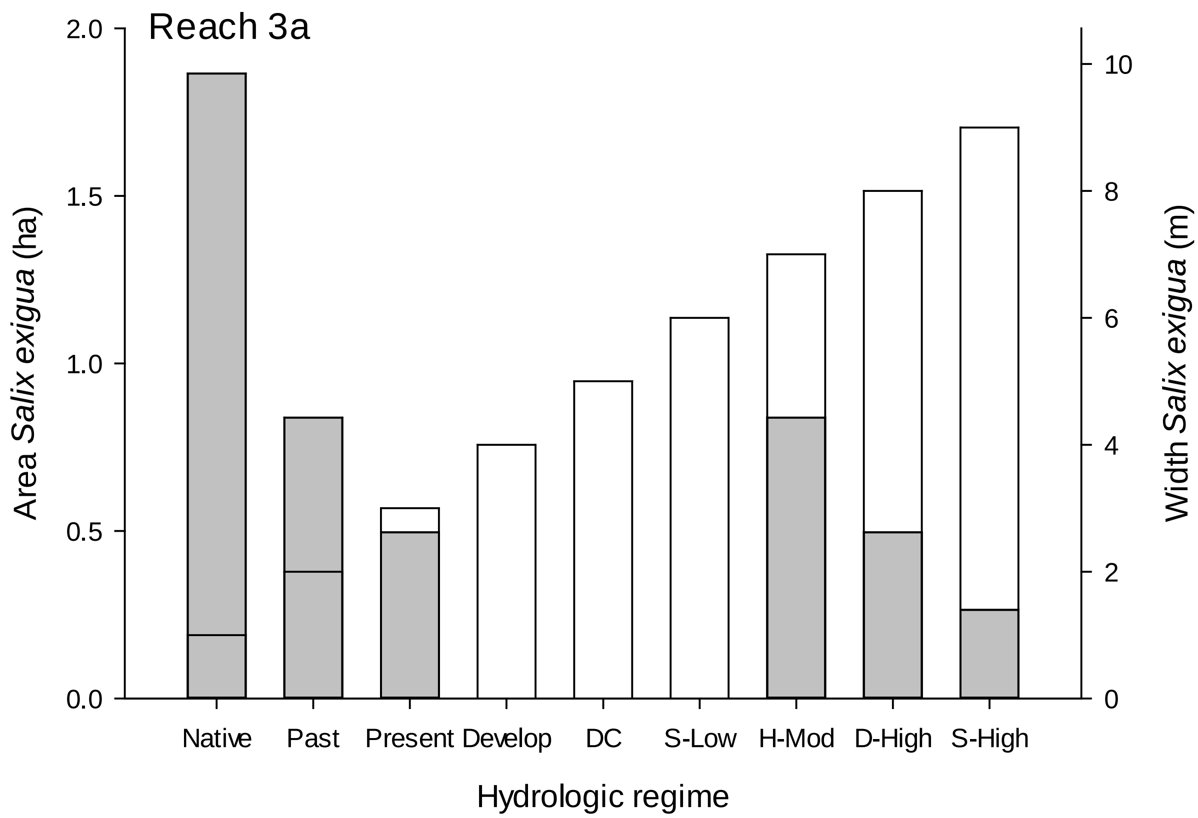

Figure B5.8: Predicted areal extent (in hectares) and average width (area divided by reach length in meters) for *Salix exigua* in Reach 3b.

Note: Abbreviated scenario names represent: Reconstructed Native (Native), Recent Past (Past), Present Operations (Present), Additional Water Development (Develop), Driest Climate (DC), StableBase-LowPeak (S-Low), HighBase-ModeratePeak (H-Mod), DryBase-HighPeak (D-High), and StableBase-HighPeak (S-High) scenarios (refer to text for full descriptions of scenarios).

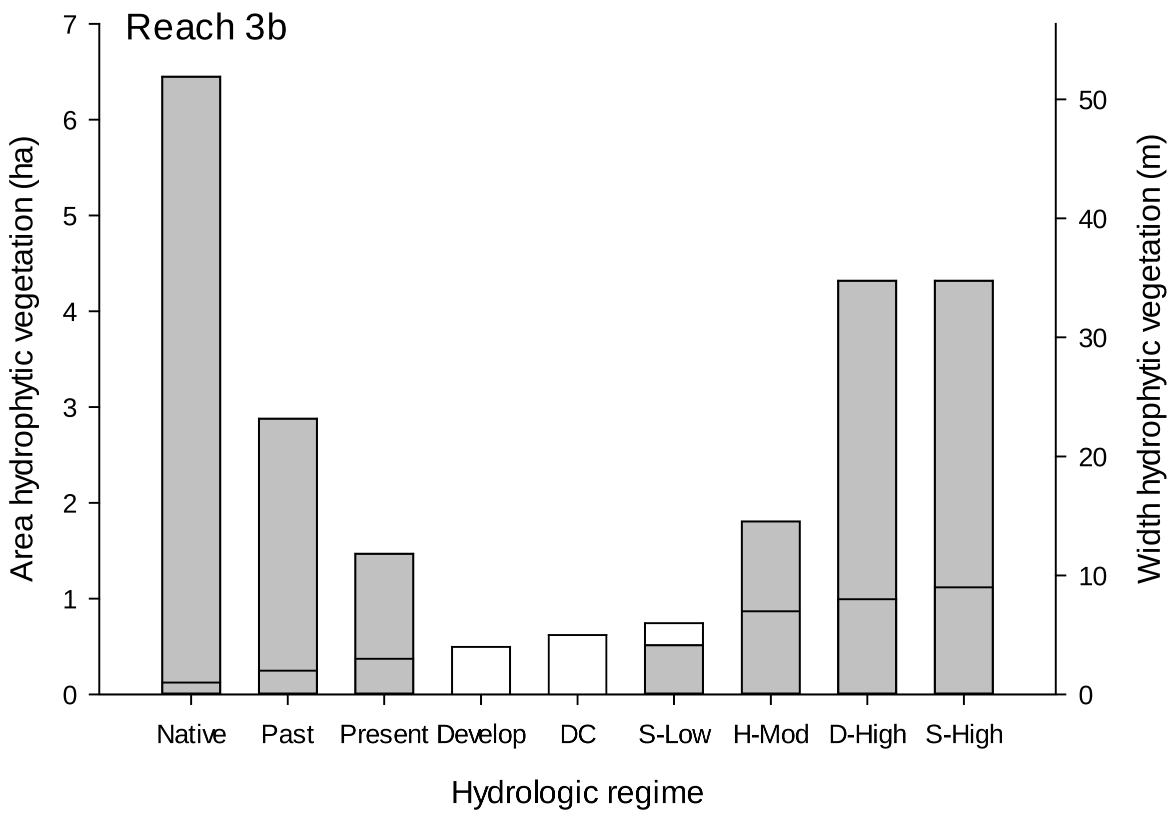

Figure B5.9: Predicted areal extent (in hectares) and average width (areal extent divided by reach length in meters) for hydrophytic vegetation in Reach 3b.

Note: Abbreviated scenario names represent: Reconstructed Native (Native), Recent Past (Past), Present Operations (Present), Additional Water Development (Develop), Driest Climate (DC), StableBase-LowPeak (S-Low), HighBase-ModeratePeak (H-Mod), DryBase-HighPeak (D-High), and StableBase-HighPeak (S-High) scenarios (refer to text for full descriptions of scenarios).

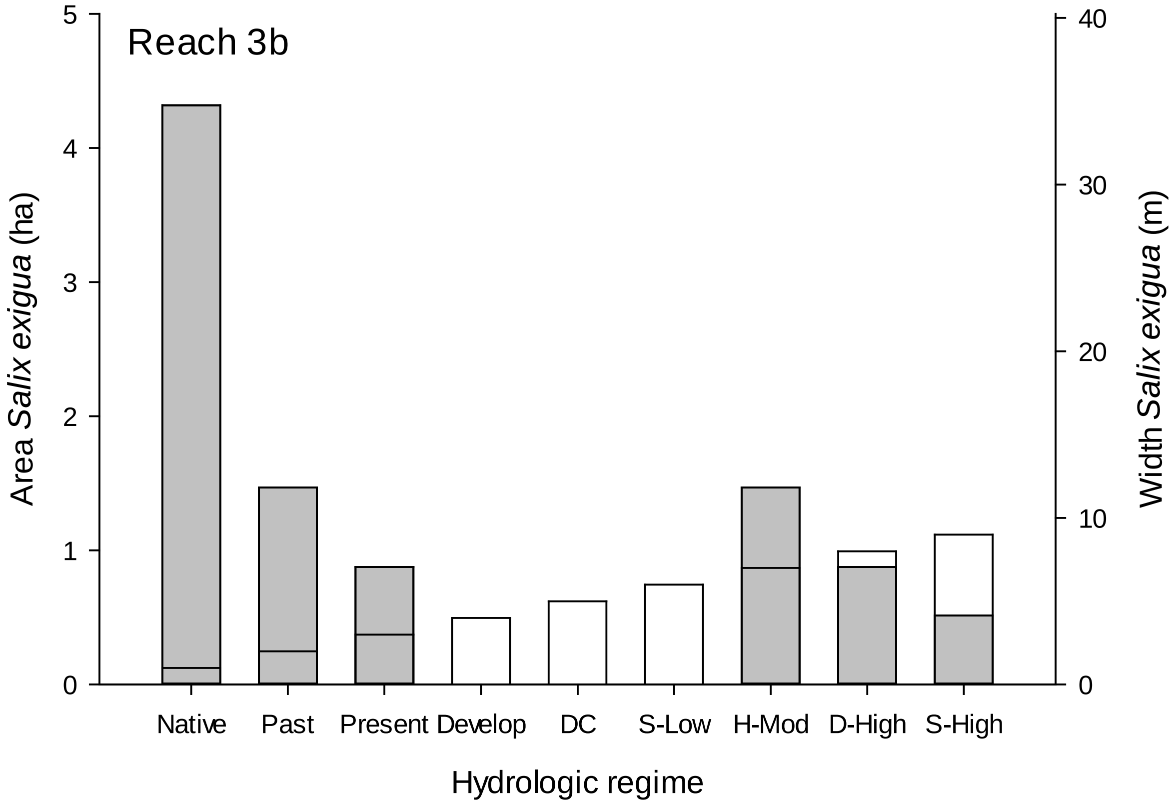

Figure B5.10: Predicted areal extent (in hectares) and average width (areal extent divided by reach length in meters) for *Salix exigua* in Reach 3b

Note: Abbreviated scenario names represent: Reconstructed Native (Native), Recent Past (Past), Present Operations (Present), Additional Water Development (Develop), Driest Climate (DC), StableBase-LowPeak (S-Low), HighBase-ModeratePeak (H-Mod), DryBase-HighPeak (D-High), and StableBase-HighPeak (S-High) scenarios (refer to text for full descriptions of scenarios).

Figure B5.11: Probability of *Salix exigua* (sandbar willow) along the Poudre River Reach 7 as a function of exceedance probability for Recent Past (baseline) flow.

Note: Predicted occurrence of S. exigua is 5.1 ha (14 m wide) along Reach 7 under the historic flow regime.

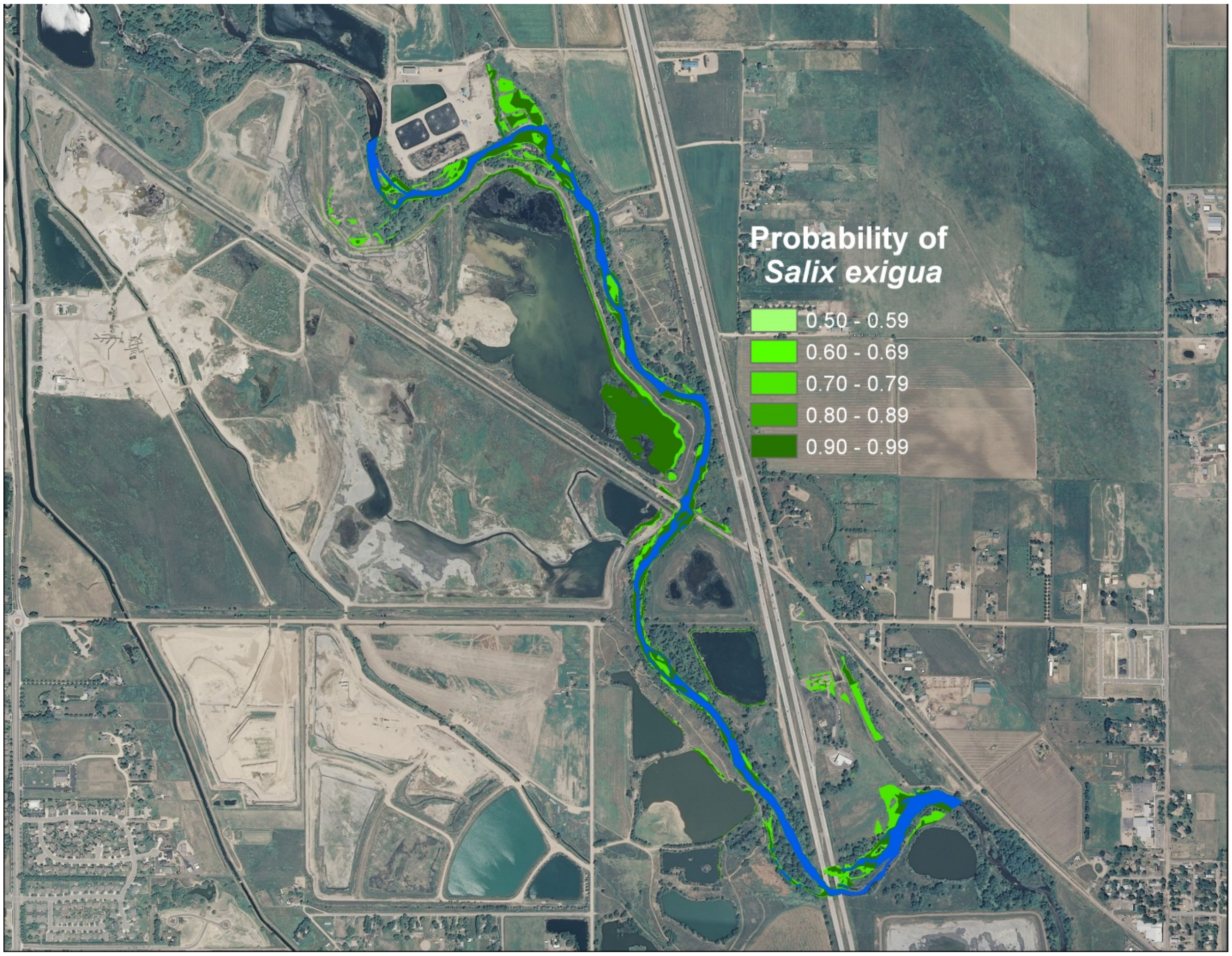

Figure B5.12: Probability of *Salix exigua* along Poudre River Reach 7 as a function of exceedance probability for Reconstructed Native flows (reconstructed flow record without flow diversions).

Note: Predicted occurrence of* S. exigua *is 14.1 ha (39 m average width) along Reach 7 under the Recent Past regime.

Figure B5.13: Probability of *Salix exigua* along Poudre River Reach 7 as a function of exceedance probability for Reconstructed Native flow.

Note: Predicted occurrence of* S. exigua *is 1.4 ha (3.8 m average width) along Reach 7 under the Recent Past regime.

Figure B5.14: Probability of *Salix exigua* along Poudre River Reach 7 as a function of exceedance probability for Additional Water Development flow.

Note: No* S. exigua *cover is predicted along Reach 7 for this scenario; the highest predicted probability of occurrence was 0.51 (7.5 ha).

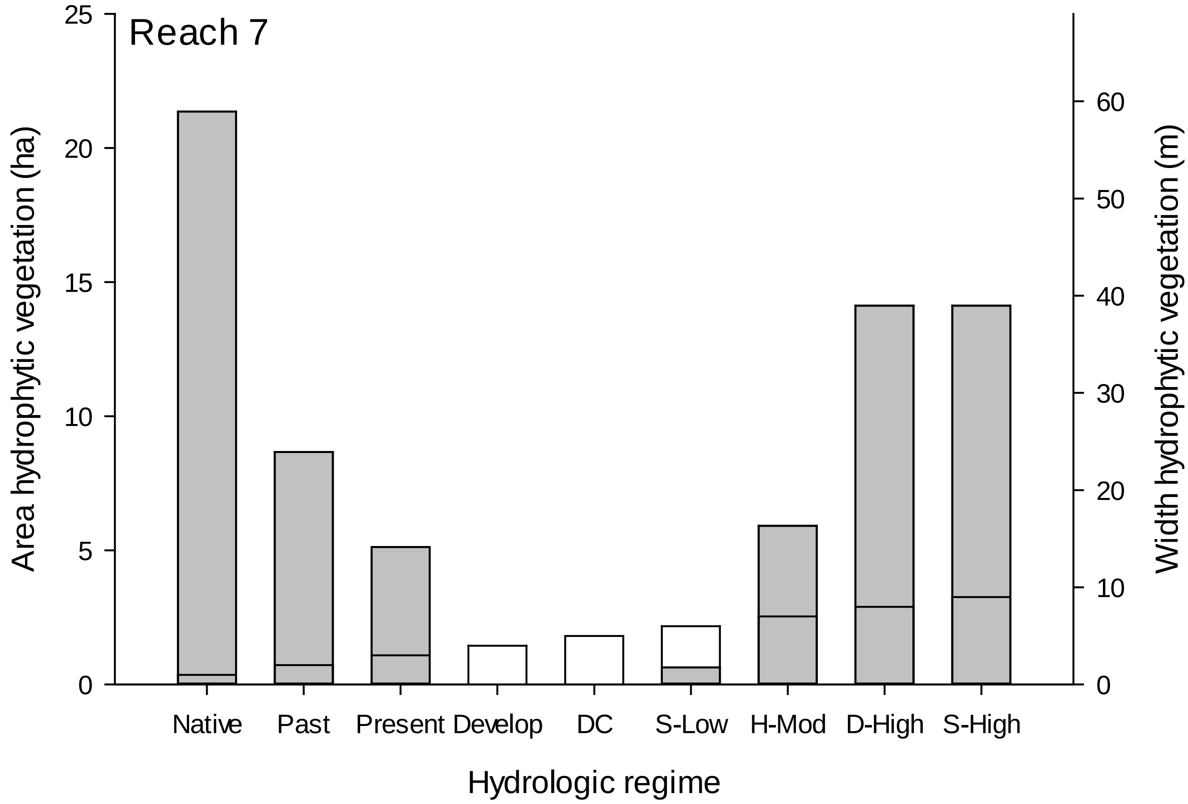

Figure B5.15: Predicted areal extent (in hectares) and average width (areal extent divided by reach length in meters) for hydrophytic vegetation in Reach 7.

Note: Abbreviated scenario names represent: Reconstructed Native (Native), Recent Past (Past), Present Operations (Present), Additional Water Development (Develop), Driest Climate (DC), StableBase-LowPeak (S-Low), HighBase-ModeratePeak (H-Mod), DryBase-HighPeak (D-High), and StableBase-HighPeak (S-High) scenarios (refer to text for full descriptions of scenarios).

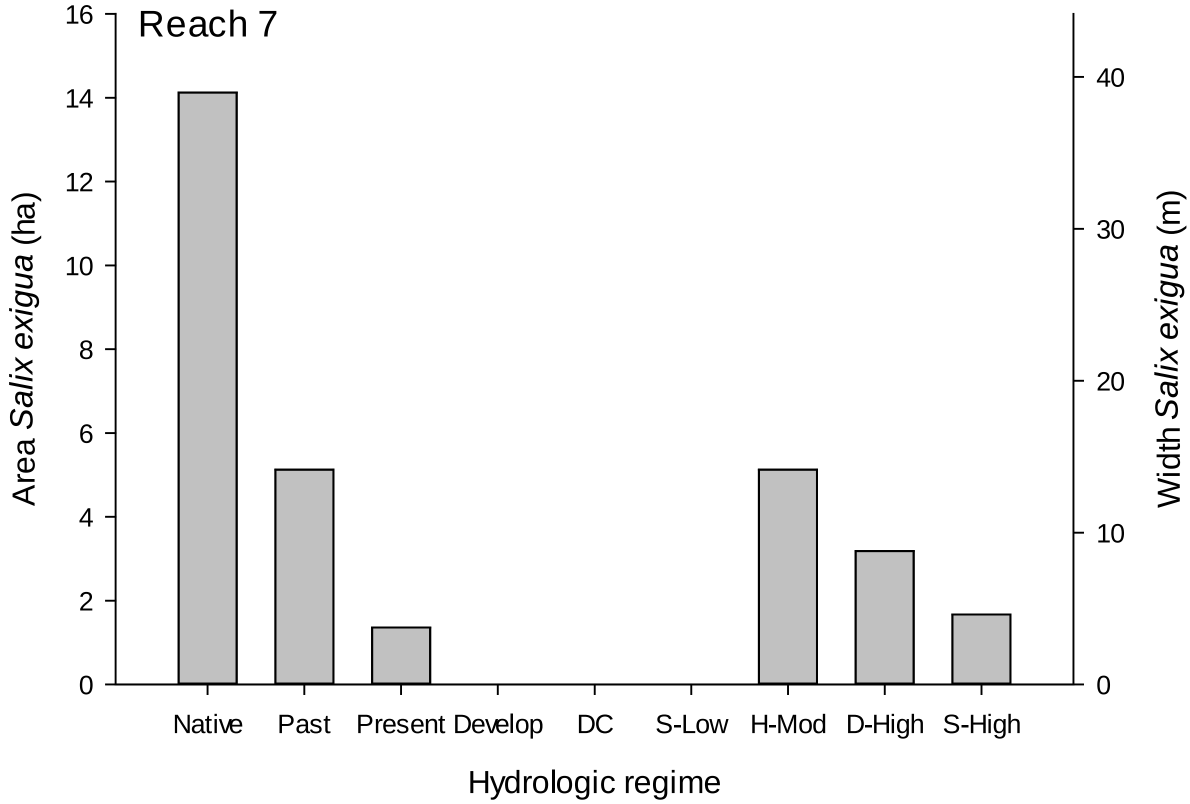

Figure B5.16: Predicted areal extent (in hectares) and average width (areal extent divided by reach length in meters) for *Salix exigua* in Reach 7

Note: Abbreviated scenario names represent: Reconstructed Native (Native), Recent Past (Past), Present Operations (Present), Additional Water Development (Develop), Driest Climate (DC), StableBase-LowPeak (S-Low), HighBase-ModeratePeak (H-Mod), DryBase-HighPeak (D-High), and StableBase-HighPeak (S-High) scenarios (refer to text for full descriptions of scenarios).

Conclusions for the Riparian Vegetation Probabilistic Modeling

Exceedance probability was a good predictor of the presence-absence of both hydrophytic vegetation (riverine wetland) and *Salix exigua*, as it provides a meaningful measure of water availability to riparian vegetation, as well as the probability of extreme high- and low-flow events. In most all cases, vegetation cover types were predicted to be highest in areal extent and average width in the Reconstructed Native flow scenario, followed by Recent Past (baseline), HighBase-ModeratePeak, DryBase-HighPeak, StableBase-HighPeak, Present Operations and Additional Water Development flow scenarios (descending cover). The most extreme cases were those of *S. exigua* in Reach 7 that completely disappeared from the reach under Additional Water Development (Figures B.21 and B.23) and hydrophytic cover in Additional Water Development and Driest Climate scenarios (no predicted cover). It is clear that the area of available habitat for both hydrophytic vegetation and *S. exigua* is greater along less constrained Reach 7 (Figures B.19 and B.23). Reaches 3a and 3b are more confined by levees and armored banks, so the area of available habitat is limited; changes in *S. exigua* cover as a function of flow are correspondingly lower. Predicted cover of hydrophytic vegetation was higher along all the reaches under the Reconstructed Native flow scenario, increasing from 68 to 146% from Recent Past. Present Operations resulted in decreases in wetland area of 40, 49, and 41% along Reaches 3a, 3b, and 7, respectively. Driest Climate resulted in elimination of hydrophytic and *Salix exigua* cover along all reaches. *S. exigua* was predicted to decrease along reach 3a (-40%) in comparing the Recent Past scenario to Present Operations, and *S. exigua* declined significantly along Reach 3b (-49%) and Reach 7 (-73%). Both cover types declined 100% in cover under Additional Water Development. Additional Water Development and Driest Climate had the most negative consequences for both riparian cover types evaluated, given all nine scenarios. Clearly, reduced magnitude and duration of peak flow and reduced low flow during the growing season lead to reduced cover and extent of hydrophytes and disturbance-adapted species such as *S. exigua*. The DryBase-HighPeak scenario and the StableBase-HighPeak scenario both improved conditions for wetland cover over Recent Past (and Present Operations, Additional Water Development, and Driest Climate), but these improvements were much more significant for the less-confined Reaches 3b and 7 compared to confined Reach 3a. *S. exigua* maintained cover relative to historic flows under the HighBase-ModeratePeak flow regime, but declined under all other modeled flow regimes.

Both low and high flows are important for riparian tree establishment and maintenance as well as for other important floodplain processes. High flows play an important role in creating and maintaining the channel and channel forms as well as maintaining dynamic and heterogeneous physical habitat for vegetation and wildlife in riparian areas (Stromberg *et al*., 2007). High flows create and maintain bare, exposed sites for seedlings of disturbance-adapted, native riparian species (e.g., *P. deltoides* and *S. exigua*). Occasional high flows mediate regeneration, are necessary for maintenance of growth and vigor of vegetation, and support the long-term sustainability of the riparian forests along the Poudre River. High flows also recharge groundwater, moisten the soil column, maintain fine roots of vegetation in the soil column, and facilitate decomposition, nutrient cycling, and nutrient availability to plants (Molles *et al*., 1998). Through moistening the soil column and elevating groundwater levels, high flows serve to exclude upland species from riparian areas, reducing competition with native riparian species and maintaining riparian areas that are distinct from adjacent uplands (Molles *et al*., 1998; Merritt and Bateman, 2012).

Sufficient low flows capable of supporting shallow water tables can increase the likelihood of establishment of disturbance-adapted species following scouring floods and support root development, growth, and survival to reproductive age (Mahoney and Rood, 1998; Merritt *et al*., 2010).

Reaches that are unconfined by riprap, bank armoring, and other structures may experience beneficial flooding of the floodplain during higher (even moderately high) flows. Appropriately timed high-flow pulses (e.g., in the spring when native riparian forest species are dispersing seed) and gradually receding flows are important biologically. Spring and summer flow pulses result in brief rises in groundwater levels which recharge and moisten the soil column and the plant roots within it, and enhance transpiration and growth of riparian vegetation.

Prolonged periods without overbank flooding along the Poudre River would lead to accumulation of organic material on the floodplain (litter and wood), increased fuel accumulation and potential for intense wildfires, nutrient limitations for some species, drier soils, lowering of water tables, and amplified water stress for phreatophytic and wetland vegetation during periods of low streamflow. Lack of flooding would also result in higher probability of shifts towards shrub-dominated vegetation in areas nearer the channel. Occasional high flows are necessary for maintenance of growth and vigor as well as the long-term sustainability of the riparian forests along the Poudre River.

The ERM's probabilistic models use existing relationships between riparian vegetation cover types to predict probable changes in these cover types as a function of changes in flow scenarios in the Poudre River. Though only nine scenarios were presented in this work, these models may be used to predict areal extent and average width of hydrophytic (riparian wetland) vegetation and *S. exigua* (dynamic mosaic) for any scenario for which exceedance probability can be calculated.

RIPARIAN BAYESIAN MODEL VARIABLES: METHODS

The structure of the integrated Bayesian model dictated categorical variables and calculations that could be easily represented by combinations of tables. The definitions and general logic of those riparian variables are presented in Section II. This appendix provides more detail on the calculations and intermediate tables. Although the Bayesian network variables and calculations are structured differently than the geospatial probability models described above, both approaches have the same foundation – application of a hydraulic model to flow sequences in order to overlay water surfaces on a channel and bottomland topography followed by estimation of the resulting pattern of physical characteristics and consequent vegetation distribution.

Rejuvenating Mosaic

This index of the creation of fluvial disturbance patches supporting establishment of new pioneer species is the product of three components: area of high potential for turnover (1 in 5-year floodplain); expected average days per year of channel movement based on dimensionless critical shear stress; and a reduction factor for anthropogenic bank stabilization. The area of high potential is obtained by the flow-width relationships applied to the 1 in 5-year annual maximum daily flows and is summarized based on four classes (Tables B.9 and B.10).

Table B5.1: Classes of 1 in 5-year floodplain width.

1 in 5-year floodplain width class	Average width in m (total area / channel length)
Minimal	<15
Narrow	15–45
Moderate	45–90
Wide	>90

Note: Widths include both sides of channel and represent total area divided by channel length.

Table B5.2: Relationship of 1 in 5-year annual maximum daily discharge and class of 1 in 5-year floodplain width.

1 in 5-year maximum daily discharge	Reach 3a	Reach 3b	Reach 7
<200	Minimal	Minimal	Minimal
200	Minimal	Minimal	Minimal
300	Minimal	Minimal	Minimal
400	Minimal	Minimal	Minimal
500	Minimal	Minimal	Minimal
600	Minimal	Minimal	Minimal
700	Minimal	Minimal	Minimal
800	Minimal	Minimal	Minimal
900	Minimal	Minimal	Minimal
1000	Minimal	Minimal	Narrow
1500	Minimal	Narrow	Narrow
2000	Minimal	Narrow	Moderate
2500	Minimal	Narrow	Moderate
3000	Narrow	Moderate	Wide
3500	Narrow	Moderate	Wide
4000	Narrow	Wide	Wide
4500	Narrow	Wide	Wide
5000	Narrow	Wide	Wide
5500	Narrow	Wide	Wide
6000	Narrow	Wide	Wide
6500	Moderate	Wide	Wide
7000	Moderate	Wide	Wide

Average expected days per year of channel movement is based on reach-specific daily values of dimensionless shear stress (τ_*) following calculations described in Appendix B1. A piecewise non-linear function relates daily dimensionless shear stress to daily probability of channel movement (Figure B.24). Probability of channel movement is zero for $\tau_* < 0.03$ and a minimal 0.001 for τ_* between 0.03 and 0.045. Above the threshold of $\tau_* = 0.045$, probability of movement increases from 0.1 at $\tau_* = 0.045$ to a maximum of 1.0 at $\tau_* = 0.06$. The non-linear increase is proportional to $(\tau_* / 0.045)^3$. Individual daily probabilities of channel movement are then used to calculate the average expected days of channel movement per year.

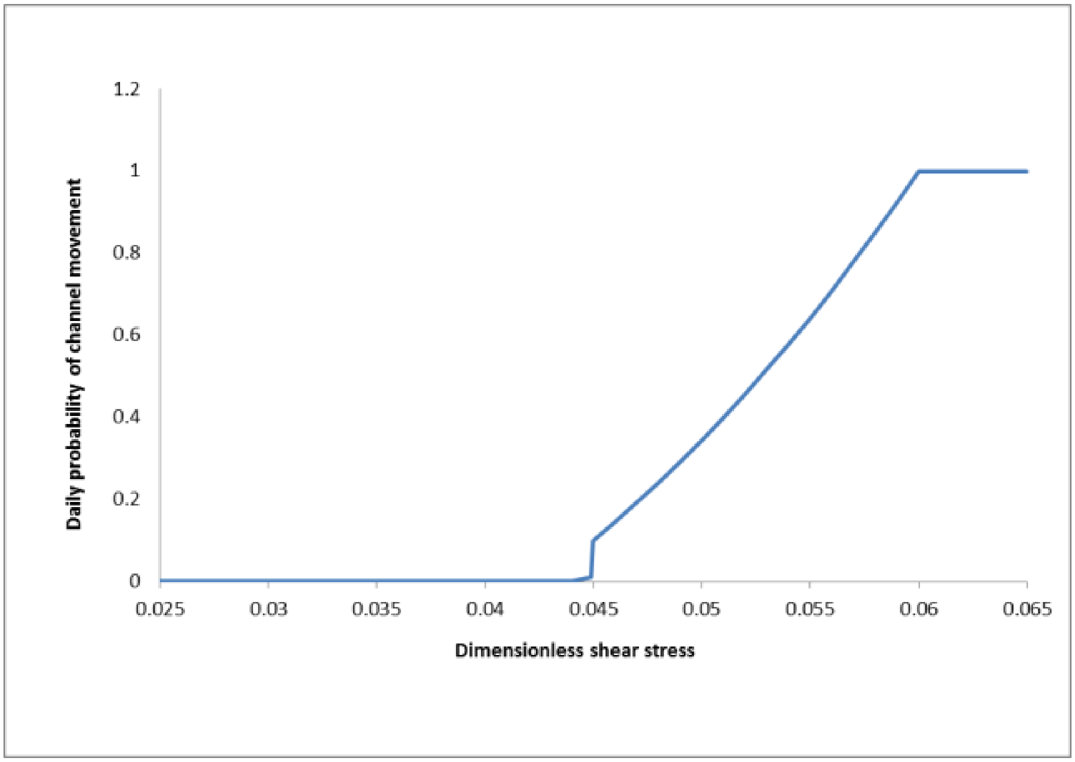

Figure B5.17: Relationship between daily probability of channel movement and dimensionless shear stress used in Bayesian Rejuvenating Mosaic calculation.

Reduction factors due to class of channel stabilization are presented in Table B.11.

Table B5.3: Reduction factor due to channel stabilization.

Class	Fractional reduction in width of Rejuvenating Mosaic
Minimal	0.92
Altered	0.58
Protected	0.33
Stabilized	0.04

Note: Current values for Reaches 3a, 3b, and 7 are Protected, Protected, and Altered, respectively.

In the Bayesian model, three factors are combined in a reach-specific table relating output state of Rejuvenating Mosaic to width class of potential turnover: the 1 in 5-year floodplain; class of likely channel movement (as determined by dimensionless shear stresses); and class of channel stabilization (Table B.12).

Table B5.4: Bayesian network table for Rejuvenating Mosaic.

Class of expected annual days of movement	Class of channel stabilization	Class of 5-yr floodplain width	Probabilities of Rejuvenating Mosaic class: Minimal	Small	Moderate	Substantial
None	Minimal	Minimal	1	0	0	0
None	Minimal	Narrow	1	0	0	0
None	Minimal	Moderate	1	0	0	0
None	Minimal	Wide	1	0	0	0
None	Altered	Minimal	1	0	0	0
None	Altered	Narrow	1	0	0	0
None	Altered	Moderate	1	0	0	0
None	Altered	Wide	1	0	0	0
None	Protected	Minimal	1	0	0	0
None	Protected	Narrow	1	0	0	0
None	Protected	Moderate	1	0	0	0
None	Protected	Wide	1	0	0	0
None	Stabilized	Minimal	1	0	0	0
None	Stabilized	Narrow	1	0	0	0
None	Stabilized	Moderate	1	0	0	0
None	Stabilized	Wide	1	0	0	0
Rare	Minimal	Minimal	0.48	0.52	0	0
Rare	Minimal	Narrow	0.04	0.96	0	0
Rare	Minimal	Moderate	0	0.54	0.46	0
Rare	Minimal	Wide	0	0.25	0.52	0.23
Rare	Altered	Minimal	0.82	0.18	0	0
Rare	Altered	Narrow	0.13	0.87	0	0
Rare	Altered	Moderate	0	0.92	0.08	0
Rare	Altered	Wide	0	0.47	0.53	0
Rare	Protected	Minimal	1	0	0	0
Rare	Protected	Narrow	0.3	0.7	0	0
Rare	Protected	Moderate	0.08	0.92	0	0
Rare	Protected	Wide	0	0.91	0.09	0
Rare	Stabilized	Minimal	1	0	0	0
Rare	Stabilized	Narrow	1	0	0	0
Rare	Stabilized	Moderate	1	0	0	0
Rare	Stabilized	Wide	0.73	0.27	0	0
Infrequent	Minimal	Minimal	0.02	0.98	0	0
Infrequent	Minimal	Narrow	0	0.19	0.43	0.38
Infrequent	Minimal	Moderate	0	0.03	0.19	0.78

Table B5.4: Bayesian network table for Rejuvenating Mosaic.

Class of expected annual days of movement	Class of channel stabilization	Class of 5-yr floodplain width	Probabilities of Rejuvenating Mosaic class: Minimal	Small	Moderate	Substantial
Infrequent	Minimal	Wide	0	0	0.07	0.93
Infrequent	Altered	Minimal	0.08	0.92	0	0
Infrequent	Altered	Narrow	0	0.36	0.64	0
Infrequent	Altered	Moderate	0	0.1	0.31	0.59
Infrequent	Altered	Wide	0	0.01	0.17	0.82
Infrequent	Protected	Minimal	0.22	0.78	0	0
Infrequent	Protected	Narrow	0	0.71	0.29	0
Infrequent	Protected	Moderate	0	0.26	0.54	0.2
Infrequent	Protected	Wide	0	0.1	0.3	0.6
Infrequent	Stabilized	Minimal	1	0	0	0
Infrequent	Stabilized	Narrow	0.57	0.43	0	0
Infrequent	Stabilized	Moderate	0.2	0.8	0	0
Infrequent	Stabilized	Wide	0.07	0.93	0	0
Occasional	Minimal	Minimal	0	0.45	0.55	0
Occasional	Minimal	Narrow	0	0.04	0.21	0.75
Occasional	Minimal	Moderate	0	0	0.05	0.95
Occasional	Minimal	Wide	0	0	0	1
Occasional	Altered	Minimal	0	0.77	0.23	0
Occasional	Altered	Narrow	0	0.12	0.33	0.55
Occasional	Altered	Moderate	0	0	0.14	0.86
Occasional	Altered	Wide	0	0	0.04	0.96
Occasional	Protected	Minimal	0.05	0.95	0	0
Occasional	Protected	Narrow	0	0.28	0.57	0.15
Occasional	Protected	Moderate	0	0.07	0.25	0.68
Occasional	Protected	Wide	0	0	0.14	0.86
Occasional	Stabilized	Minimal	0.53	0.47	0	0
Occasional	Stabilized	Narrow	0.21	0.79	0	0
Occasional	Stabilized	Moderate	0.04	0.96	0	0
Occasional	Stabilized	Wide	0	0.69	0.31	0

Functional Riparian Zone

Table B.13 summarizes the relationship between discharge exceeded one day in two years of growing season days (0.0033 exceedance) and class of Functional Riparian Ecosystem area.

Table B5.5: Bayesian network table relating discharge to states of Functional Riparian Ecosystem (width classes) by selected reach.

Reach	Discharge (cfs)	Probability by width class[a]			
		Minimal	Narrow	Moderate	Wide
3a	200	1	0	0	0
3a	300	1	0	0	0
3a	400	1	0	0	0
3a	500	1	0	0	0
3a	600	1	0	0	0
3a	700	1	0	0	0
3a	800	1	0	0	0
3a	900	1	0	0	0
3a	1000	1	0	0	0
3a	1500	0.92	0.08	0	0
3a	2000	0.61	0.39	0	0
3a	2500	0.44	0.56	0	0
3a	3000	0.35	0.65	0	0
3a	3500	0.29	0.71	0	0
3a	4000	0.23	0.77	0	0
3a	4500	0.15	0.85	0	0
3a	5000	0.02	0.98	0	0
3a	5500	0	0.95	0.05	0
3a	6000	0	0.64	0.36	0
3a	6500	0	0.38	0.62	0
3a	7000	0	0.22	0.78	0
3b	200	1	0	0	0
3b	300	1	0	0	0
3b	400	1	0	0	0
3b	500	1	0	0	0
3b	600	1	0	0	0
3b	700	1	0	0	0
3b	800	1	0	0	0
3b	900	0.89	0.11	0	0
3b	1000	0.66	0.34	0	0
3b	1500	0.16	0.84	0	0
3b	2000	0	0.77	0.23	0
3b	2500	0	0.4	0.6	0
3b	3000	0	0.12	0.72	0.16
3b	3500	0	0	0.53	0.47
3b	4000	0	0	0.3	0.7
3b	4500	0	0	0.16	0.84
3b	5000	0	0	0.04	0.96
3b	5500	0	0	0	1

Table B5.5: Bayesian network table relating discharge to states of Functional Riparian Ecosystem (width classes) by selected reach.

Reach	Discharge (cfs)	Probability by width class[a]			
		Minimal	Narrow	Moderate	Wide
3b	6000	0	0	0	1
3b	6500	0	0	0	1
3b	7000	0	0	0	1
7	200	1	0	0	0
7	300	1	0	0	0
7	400	1	0	0	0
7	500	0.69	0.31	0	0
7	600	0.46	0.54	0	0
7	700	0.32	0.68	0	0
7	800	0.19	0.81	0	0
7	900	0.11	0.89	0	0
7	1000	0.03	0.97	0	0
7	1500	0	0.55	0.45	0
7	2000	0	0.16	0.76	0.08
7	2500	0	0	0.54	0.46
7	3000	0	0	0.32	0.68
7	3500	0	0	0.2	0.8
7	4000	0	0	0.12	0.88
7	4500	0	0	0.05	0.95
7	5000	0	0	0	1
7	5500	0	0	0	1
7	6000	0	0	0	1
7	6500	0	0	0	1
7	7000	0	0	0	1

[a] Width classes: Minimal (< 15 m); Narrow (15–45 m); Moderate (45–90 m); and Wide (> 90 m).

Riverine Wetland

Table B.14 summarizes the relationship between discharge exceeded 5% of the growing season and class of Riverine Wetland area (expressed as width to normalize for different channel lengths).

Table B5.6: Bayesian network table relating discharge to Riverine Wetland states (width classes) by selected reach.

		Probability by width class[a]			
Reach	**Discharge (cfs)**	**Minimal**	**Narrow**	**Moderate**	**Wide**
3a	200	1	0	0	0
3a	300	1	0	0	0
3a	400	1	0	0	0
3a	500	0.83	0.17	0	0
3a	600	0.54	0.46	0	0
3a	700	0.36	0.64	0	0
3a	800	0.23	0.77	0	0
3a	900	0.14	0.86	0	0
3a	1000	0.08	0.92	0	0
3a	1500	0	0.92	0.08	0
3a	2000	0	0.61	0.39	0
3a	2500	0	0.44	0.56	0
3a	3000	0	0.35	0.65	0
3a	3500	0	0.29	0.71	0
3a	4000	0	0.23	0.77	0
3a	4500	0	0.15	0.75	0.09
3a	5000	0	0.03	0.62	0.35
3a	5500	0	0	0.43	0.57
3a	6000	0	0	0.22	0.78
3a	6500	0	0	0.05	0.95
3a	7000	0	0	0	1
3b	200	1	0	0	0
3b	300	1	0	0	0
3b	400	1	0	0	0
3b	500	0.65	0.35	0	0
3b	600	0.38	0.62	0	0
3b	700	0.15	0.85	0	0
3b	800	0	1	0	0
3b	900	0	0.89	0.11	0
3b	1000	0	0.66	0.34	0
3b	1500	0	0.16	0.76	0.08
3b	2000	0	0	0.31	0.69
3b	2500	0	0	0.07	0.93
3b	3000	0	0	0	1
3b	3500	0	0	0	1
3b	4000	0	0	0	1
3b	4500	0	0	0	1
3b	5000	0	0	0	1
3b	5500	0	0	0	1
3b	6000	0	0	0	1
3b	6500	0	0	0	1
3b	7000	0	0	0	1

Table B5.6: Bayesian network table relating discharge to Riverine Wetland states (width classes) by selected reach.

		Probability by width class[a]			
Reach	**Discharge (cfs)**	**Minimal**	**Narrow**	**Moderate**	**Wide**
7	200	1	0	0	0
7	300	0.49	0.51	0	0
7	400	0	1	0	0
7	500	0	0.69	0.31	0
7	600	0	0.46	0.54	0
7	700	0	0.32	0.68	0
7	800	0	0.20	0.79	0.01
7	900	0	0.11	0.71	0.18
7	1000	0	0.03	0.63	0.34
7	1500	0	0	0.17	0.83
7	2000	0	0	0	1
7	2500	0	0	0	1
7	3000	0	0	0	1
7	3500	0	0	0	1
7	4000	0	0	0	1
7	4500	0	0	0	1
7	5000	0	0	0	1
7	5500	0	0	0	1
7	6000	0	0	0	1
7	6500	0	0	0	1
7	7000	0	0	0	1

[a] Width classes: Minimal (< 5 m); Narrow (5–15 m); Moderate (15–30 m); and Wide (> 30 m).

APPENDIX C: MODEL RESULTS

Tables C.1–C.8 display the comprehensive set of results for each of eight biological indicators in relation to the various hydrology scenarios studied through the ERM.

Table C.1: Comprehensive results for Channel Structure in each scenario, separated by the reach of the river.

CHANNEL STRUCTURE										
Reach	Scenario → Condition ↓	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	- -	0%	26%	100%	100%	100%	100%	100%	0%	0%
	-	8%	50%	0%	0%	0%	0%	0%	8%	6%
	0	42%	22%	0%	0%	0%	0%	0%	42%	44%
	+	50%	2%	0%	0%	0%	0%	0%	50%	50%
3B	- -	0%	4%	91%	100%	100%	100%	0%	0%	0%
	-	8%	32%	9%	0%	0%	0%	85%	8%	8%
	0	42%	50%	0%	0%	0%	0%	14%	42%	42%
	+	50%	14%	0%	0%	0%	0%	0%	50%	50%
7	- -	0%	0%	38%	99%	100%	1%	0%	0%	0%
	-	2%	2%	46%	1%	0%	93%	11%	2%	2%
	0	22%	22%	15%	0%	0%	6%	83%	22%	22%
	+	76%	76%	1%	0%	0%	0%	6%	76%	76%

Table C.2: Comprehensive results for Algae in each scenario, separated by the reach of river.

ALGAE										
Reach	Scenario → Condition ↓	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	-	10%	50%	50%	100%	100%	100%	30%	10%	10%
	0	20%	40%	40%	0%	0%	0%	50%	40%	40%
	+	70%	10%	10%	0%	0%	0%	20%	50%	50%
3B	-	10%	50%	50%	100%	100%	100%	30%	10%	10%
	0	20%	40%	40%	0%	0%	0%	50%	40%	40%
	+	70%	10%	10%	0%	0%	0%	20%	50%	50%
7	-	0%	50%	50%	50%	100%	80%	20%	10%	10%
	0	10%	40%	40%	40%	0%	20%	40%	40%	40%
	+	90%	10%	10%	10%	0%	0%	40%	50%	50%

Table C.3: Comprehensive results for Aquatic Insects in each scenario, separated by the reach of river.

AQUATIC INVERTEBRATES										
Reach	Scenario → Condition ↓	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	-	30%	50%	50%	58%	58%	46%	30%	35%	18%
	0	48%	48%	48%	42%	42%	48%	58%	48%	57%
	+	23%	2%	2%	0%	0%	6%	12%	17%	25%
3B	-	30%	48%	50%	58%	58%	46%	30%	35%	18%
	0	48%	48%	48%	42%	42%	48%	58%	48%	57%
	+	22%	4%	2%	0%	0%	6%	12%	17%	25%
7	-	25%	38%	50%	50%	58%	42%	24%	31%	14%
	0	46%	48%	48%	48%	42%	51%	57%	48%	57%
	+	30%	14%	2%	2%	0%	6%	19%	21%	29%

Table C.4: Comprehensive results for Native Fish in each scenario, separated by the reach of river.

NATIVE FISH										
Reach	Scenario → Condition ↓	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	- -	29%	33%	44%	44%	44%	37%	37%	30%	20%
	-	26%	32%	28%	29%	29%	28%	26%	27%	25%
	0	25%	26%	21%	20%	20%	23%	23%	25%	28%
	+	20%	9%	7%	7%	7%	13%	14%	18%	27%
3B	- -	29%	29%	43%	44%	44%	37%	20%	30%	21%
	-	26%	32%	29%	29%	29%	28%	34%	27%	25%
	0	25%	26%	21%	20%	20%	23%	31%	25%	28%
	+	20%	12%	7%	7%	7%	13%	15%	18%	26%
7	- -	18%	25%	35%	44%	45%	18%	4%	25%	2%
	-	20%	24%	32%	29%	29%	36%	34%	23%	17%
	0	29%	26%	24%	20%	19%	31%	33%	27%	34%
	+	33%	25%	9%	7%	7%	15%	29%	26%	47%

Table C.5: Comprehensive results for Brown Trout in each scenario, separated by the reach of river.

TROUT										
Reach	Scenario → Condition ↓	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	- -	19%	42%	64%	65%	65%	37%	24%	43%	6%
	-	16%	30%	19%	19%	19%	30%	24%	14%	16%
	0	30%	23%	14%	13%	13%	22%	25%	22%	34%
	+	36%	5%	3%	2%	2%	11%	27%	21%	45%
3B	- -	19%	38%	63%	65%	65%	37%	8%	43%	6%
	-	16%	27%	19%	19%	19%	30%	30%	14%	16%
	0	30%	25%	15%	13%	13%	22%	36%	22%	34%
	+	35%	10%	3%	2%	2%	11%	26%	21%	44%
7	- -	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0	0%	0%	0%	0%	0%	0%	0%	0%	0%
	+	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table C.6: Comprehensive results for Rejuvenating Mosaic in each scenario, separated by the reach of the river.

REJUVENATING MOSAIC RIPARIAN FOREST										
Reach	Scenario → Condition ↓	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	- -	0%	22%	100%	100%	100%	100%	100%	30%	30%
	-	28%	78%	0%	0%	0%	0%	0%	70%	70%
	0	57%	0%	0%	0%	0%	0%	0%	0%	0%
	+	15%	0%	0%	0%	0%	0%	0%	0%	0%
3B	- -	0%	0%	30%	100%	100%	100%	100%	8%	8%
	-	10%	71%	70%	0%	0%	0%	0%	92%	92%
	0	30%	29%	0%	0%	0%	0%	0%	0%	0%
	+	60%	0%	0%	0%	0%	0%	0%	0%	0%
7	- -	0%	0%	13%	82%	82%	100%	82%	0%	0%
	-	1%	10%	87%	18%	18%	0%	18%	47%	47%
	0	17%	31%	0%	0%	0%	0%	0%	53%	53%
	+	82%	59%	0%	0%	0%	0%	0%	0%	0%

Table C.7: Comprehensive results for Functional Riparian Ecosystem in each scenario, separated by the reach of the river.

WIDTH OF FUNCTIONING RIPARIAN ZONE										
Reach	**Scenario →** **Condition ↓**	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	- -	23%	29%	61%	100%	100%	100%	100%	35%	35%
	-	77%	71%	39%	0%	0%	0%	0%	65%	65%
	0	0%	0%	0%	0%	0%	0%	0%	0%	0%
	+	0%	0%	0%	0%	0%	0%	0%	0%	0%
3B	- -	0%	0%	0%	66%	100%	66%	100%	0%	0%
	-	0%	0%	77%	34%	0%	34%	0%	12%	12%
	0	30%	53%	23%	0%	0%	0%	0%	72%	72%
	+	70%	47%	0%	0%	0%	0%	0%	16%	16%
7	- -	0%	0%	0%	19%	32%	3%	32%	0%	0%
	-	0%	0%	55%	81%	68%	97%	68%	0%	0%
	0	20%	20%	45%	0%	0%	0%	0%	32%	32%
	+	80%	80%	0%	0%	0%	0%	0%	68%	68%

Table C.8: Comprehensive results for Riparian Wetlands in each scenario, separated by the reach of the river.

RIPARIAN WETLAND WIDTH OF RIVER DOMINATED ZONE										
Reach	**Scenario →** **Condition ↓**	*Rec. Native*	*Recent Past*	*Present Operations*	*Add' Water Dev'l*	*Driest Climate*	*StableBase-LowPeak*	*HighBase-ModeratePeak*	*DryBase-HighPeak*	*StableBase-HighPeak*
3A	- -	0%	0%	8%	100%	100%	36%	8%	0%	0%
	-	44%	92%	92%	0%	0%	64%	92%	61%	61%
	0	56%	8%	0%	0%	0%	0%	0%	39%	39%
	+	0%	0%	0%	0%	0%	0%	0%	0%	0%
3B	- -	0%	0%	0%	100%	100%	15%	0%	0%	0%
	-	0%	16%	66%	0%	0%	85%	66%	0%	0%
	0	7%	76%	34%	0%	0%	0%	34%	31%	31%
	+	93%	8%	0%	0%	0%	0%	0%	69%	69%
7	- -	0%	0%	0%	0%	100%	0%	0%	0%	0%
	-	0%	0%	11%	100%	0%	32%	3%	0%	0%
	0	0%	17%	71%	0%	0%	68%	63%	0%	0%
	+	100%	83%	18%	0%	0%	0%	34%	100%	100%

APPENDIX D: PEER REVIEW

In November of 2012 the City of Fort Collins hosted a review discussion on the ERM with the team and over twenty individuals from local agencies with expertise on Poudre River including staff from other departments within the City of Fort Collins, Colorado Parks and Wildlife, Colorado State University, and local non-profits and consulting firms. The reviewers were provided with a preliminary ERM report and the comments received through that process is presented below along with responses from the ERM team. Please note, the preliminary report was, in many aspects, considerably different from this final report.

OVERARCHING CONSIDERATIONS

Comment 1: The report does not address the most critical and pressing question across all audiences. Namely, what does this mean and what can we do about it? What potential actions must the City take to successfully manage resources under the various scenarios? There should be a social element on top of this science to inform water managers.

> ***Response 1:*** The purpose of this report is to document the process of model development and offer full results of each element of the model. Thus, the overall structure of the report will not change. Model results do not lead directly to management recommendations or to the development of specific educational messages for managers. However, considering the interest in management recommendations and the need for a simpler description of the project, a subgroup of the ERM team – lead by City staff who have management rather than science as their primary charge – may develop an independent document geared toward the management audience.

Comment 2: The tone of the report is defensive. Limitations are reported in depth and repeatedly. The report should be shorter to be more interesting and accessible to a wider audience.

> ***Response 2:*** This may have occurred as a result of nine authors trying to capture a very large modeling effort. The tone of the report has been edited as appropriate to reflect the team's confidence in the model, with duplicate statements of caveats eliminated. This report serves as a comprehensive documentation of the project and each element (hydrology input data, analyses of sub-models, formation of expert opinion into probabilities, the structure of the Bayesian model, and reporting of extensive results) and each has specific, relevant limitations. As mentioned in *Response 1*, a stand-alone summary aimed at a wider audience may be developed.

Comment 3: The authors need to be cognizant when making statements contrary to City policy and current practices. For example, the concept of anchoring large, woody debris in the river to increase habitat is contrary to several City policies and regulations. The City of Fort Collins Utilities has a policy to remove woody debris from the river to prevent the buildup of debris on bridges. The debris would have to be strategically placed to avoid flooding adjacent properties or causing unexpected erosion. Similarly, the concept of allowing channel movement in some areas of the river needs additional exploration. This concept could be workable in specific reaches of the river, but the City would need to comprehensively address and plan for constraints of private property, permitting and flood issues.

> ***Response 3:*** The final report will explicitly acknowledge those recommendations or ideas that run against City policy. The report will still include the ideas because they merit consideration if the City wants to improve conditions on the river.

Comment 4: Many of the public see the existing Poudre River as a good deal better than these results indicate.

> ***Response 4:*** The hydrology and landscape of the Poudre River through Fort Collins have been vastly altered since pre-settlement times. These changes affect the river both in space and time time. While the proximity of Fort Collins to Poudre Canyon does help to improve the health of the river through town, noteworthy shifts exist in water quality, temperature, and fish in the few short miles that the Poudre runs through Fort Collins. Second, some elements of the ecosystems such as the riparian forest respond to changing conditions on the multi-decadal to century time scale, which reflects the lifespan of deciduous trees such as cottonwood. Therefore, there is a significant lag time in the condition of this indicator in response to input parameters. For example the Present Operations scenario indicates a course of future narrowing beyond what today's field observations indicate. This becomes evident through field observations that reveal a scarcity of young native riparian trees with increasing distance from the river's edge.

Comment 5: What is the baseline? In an earlier version of the report, all the results were displayed against the poorest possible condition for each indicator. It may be a good idea to portray the current baseline in more neutral terms. Could you compare the results for all scenarios against the Reconstructed Native scenario? Or could you display the results against the baseline of Present Operations scenario?

> ***Response 5:*** There is reluctance to reference all the results on the Reconstructed Native condition because there is a significant change to the indicators under all scenarios when compared to the results for Reconstructed Native.
>
> Therefore, under such a comparison it would be hard to distinguish the differences across the scenarios most likely to occur in our future because the changes are minimized when compared to the Reconstructed Native.

Comment 6: Some biological indicators (Algae and Aquatic Insects) are presented based on a change from today's condition; the rest of the indicators are presented by a description, and the reader does not know in which state they are currently.

> ***Response 6:*** The modeling team has developed these categories based on each specific discipline, and based on data availability. All indicators were designed to cover a range of conditions which are described to the extent possible as allowed by data availability...

Comment 7: Is it correct to categorize this as a change model as opposed to an absolute results model?

> ***Response 7:*** Yes and no. The greatest confidence lies in the comparison for results between reaches and scenarios. However, the model was developed with the best available data for both input and nodes with the intention of characterizing the states for each indicator. The weakness and imprecision of the absolute results is due the process of categorizing each sub-node and the output into four "bins". This should not discount the value of the absolute results. When better

hydrologic data becomes available from EISs for the NISP and HSWSP projects, the ERM will show a parallel improvement in the absolute results.

Comment 8: Climatologists seem to concur that as climates continue to change, fires will start to become the norm rather than a temporary aberration. This report suggests fires as a short-term deviation. Maybe fires and the subsequent sediment loading of the river are not a temporary issue. The wilderness areas within national forests will not be seeded for soil stabilization; therefore, they will continue to deliver additional sediment to the Poudre for many years – even after the lower portions of the watershed have been stabilized through efforts by the cities of Fort Collins, Greeley, and others. Finally, the High Park Fire and its impact on water quality in the Poudre, specifically in regard to nutrient loading, will be very significant in both the short- and long-term. Maybe an additional paragraph on the anticipated impact in relation to the nutrient control regulations would be in order. There is more nutrient data for 2013 at several sites on the Poudre, from the mouth of the canyon to Greeley. The data includes values captured during post-fire stormwater runoff conditions.

Response 8: Fire is only one of a series of human and natural changes to the watershed that would have a profound impact on the ecological condition of the river. The ERM team could consider adding modules to address effects of perturbations like fire (for example the changes in watershed sediment supply or size, water quality alterations other than nutrients, etc.). The reality is that the data available to make probabilistic forecasts for these drivers is sparse and thus it is challenging to insert them at this time. A comprehensive list of those drivers not included in the model can be found in Section III.

Comment 9: Reducing the effect of “turning the tap on and off” to smooth out the low flows would be beneficial. The variability of low flows not only harms aquatic organisms but also is detrimental to the recreational boating and tubing experience. This important flow issue on the Poudre is not in the model but was brought up repeatedly during the peer review workshop. Coordination between the several water managers on the river to better manage its flows could possibly reduce the flashiness of the peaks on the river. There are cases where the river flows can vary by hundreds of cfs in a matter of hours.

Response 9: The model does not incorporate the impact of hourly low flow volatility on the condition of the aquatic indicators. It is unlikely that the ERM can accurately incorporate this element, and this will probably not be attempted to maintain existing level of confidence. The City of Fort Collins is working on a study directed specifically at understanding the administration, timing, and location of Poudre water rights to identify feasible solutions to dry up points and low flow volatility. The goal of that study is to explore possible simple operational changes (innocuous to water users) that could reduce the erratic behavior in the low flow months.

This topic is also discussed further towards the end of Section III on page 83 under the subtitle Influence of Low Flow Data on Modelling Process and Results

Comment 10: The Poudre provides other benefits to the surrounding communities (drinking water, agriculture, food production, etc.). The report ignores these other benefits. It needs to be made clear that it is ecosystem needs, not human needs, being discussed.

Response 10: The earlier report did not acknowledge this sufficiently, as noted by this comment. The introduction of the final report has been edited to acknowledge these benefits explicitly in the Introduction.

Comment 11: Longitudinal connectivity is not accounted for in the model and it should be if this is to be called a holistic model. Does the city view each project in isolation? For example, how might widening it in one place affect channel downstream? How does money spent on one treatment affect other treatments? How does the model deal with sediment delivery, influence of diversion structures on the dispersal of aquatic species? If not thought through carefully in advance, small-scale changes to the channel without a more global perspective can degrade fish habitat.

> ***Response 11:*** This will be noted within the City as an important consideration for its planning, local modeling needs, and evaluation of restoration projects. The ERM itself it is not structured to evaluate local changes and impacts. However, it does significantly contribute to the discussion (including the importance and role of the physical context at the local level) occurring within the City and the greater Poudre River community. This type of comment could provoke greater communication between localized projects to help assure that specific concerns are considered.

MODEL STRUCTURE

Comment 12: The model indicates there is only one main driver of river condition, namely water volume and duration, and so the discussion appears directed solely at water users. Discussion needs to be aimed at a broader audience and to highlight other inputs to the river. The model should be used to illustrate the combination of influences of hydrology with land use and development, the influence of microsite softening, land management techniques, nutrient inputs, and daily water management, to demonstrate the non-water diversion aspects of the current condition of the river. How could you characterize the return on investment given the same water flow and find other avenues for small wins? Doing so will make the model much more useful, interest a larger group of stakeholders, and make it easier to engage the water management community.

> ***Response 12:*** The project and discussion is not directed only at water users, but the project is based on the theory that flows are the master variable of river systems and the primary driver of ecosystem condition. The team and the model structure does recognize a broad spectrum of influential factors on this highly altered system, yet flows remain the primary input. The team may expand the explore ways to demonstrate the importance of a broader set of inputs. Specifically, the riparian element could be expanded to demonstrate a variety of static but low-lying bank management techniques and their impact on riparian outcomes.

Comment 13: Several important ecological interactions are not included in the model structure. Missing relationships include:

- The influence of riparian trees proximate to the channel for shading water, reducing temperatures, providing microhabitats for fish, insects and associated allochthonous inputs,
- Wetland macro-invertebrate inputs or model consideration,
- Scour of vegetation from higher flows and channel maintenance preventing encroachment and channel shrinkage, and
- The predatory interaction between Brown Trout and Native Species.

> ***Response 13:*** The model was structured to include the most influential relationships referred to in the report as primary influencers. The above list includes many important ecological connections that were acknowledged in the text of the report (see Section III, page 82), but excluded from the model because they were considered secondary influencers of condition.

Additionally, many of these relationships are not as well informed by empirical data in the broader knowledgebase of ecosystem science or in the Poudre basin. Thus, it was felt that inclusion would decrease the overall strength of the model.

Comment 14: Show the model algorithms. The reader cannot see the actual model calculations.

Response 14: The ERM runs on SMILE (Structural Modeling, Inference, and Learning Engine) running within the GeNIe (Graphical Network Interface) both found at http://genie.sis.pitt.edu/. As the SMILE-GeNIe model is currently set up, results are simply conditional probabilities of the categorical input data through each step of the model using the general form:

$$P(A_i|B) = \frac{P(B|A_i)P(A_i)}{P(B)} = \frac{P(B|A_i)P(A_i)}{\sum_{i=1}^{n} P(B|A_i)P(A_i)}$$

Where A and B are possible outcomes and $P(A_i|B)$ is interpreted as the conditional probability of A_i given B.

MODEL TESTING

Comment 15: Is there any way to calibrate the results to known, observed parameters?

Response 15: In short, yes. The model can be calibrated to observed conditions as that data becomes available. The probabilities developed for each sub-model also contain varying proportions of data and expert opinion. For example, the Riparian Wetlands and Brown Trout models were based on field data, while the Algae model was based on scientific understanding of the drivers of algae growth and no actual field data.

Comment 16: Is there a plan to add validation (sampling) to those areas that are based on expert opinion when empirical data is limited? How will this be tested?

Response 16: A field campaign to provide validation data is currently outside the scope and budget of this project, although the input data, methodology, and relationships have been thoroughly vetted by scientific experts in each respective field. Project managers are open to such validation as the data and/or funding becomes available.

Comment 17: How will you test the model?

Response 17: See responses to Comments15 and 16, above. Further, robust testing of each component of the model is not currently possible given data limitations. Greater confidence exists in the relative trend-prediction capabilities of the model than in its acute accuracy.

Comment 18: Using historic flows to test against current conditions is a possible test. Have you considered the results of the Recent Past scenario to current condition observed on the river?

Response 18: Yes, managers have considered (and evaluated) contrasting the projected conditions against the historic flows. One present challenge is variation (in period of record) of the available flow scenarios. Once comparable flow scenarios from the USACE's Common Technical Platform become available, this type of contrasting will hold more validity.

Hydrology Input Data and Scenarios

Comment 19: You are really projecting future flow years based on 1970–2010 Recent Past flow data. You should model the accounts better for quantity of water as opposed to timing of flows.

Response 19: Correct, potential changes to the timing of flows (such as timing of spring peak as it may be affected by changes in climate) have not been incorporated. While it would be possible to add this to the model, it would further stretch the current understanding of cause-effect relationships in the ecosystem.

Comment 20: The terms "Historic" and "Reconstructed Native" are very confusing. I recommend striving to find titles that are more descriptive of these conditions. When I hear Historic, I picture pre-European settlement conditions. Reconstructed Native to me means rebuilding back to pre-settlement conditions.

Response 20: This has been one of the most contentious discussions among the team. There is no perfect, simple title to capture these important details in the various flows scenarios. The tables and text associated provide the complete description of these scenarios and data sources.

The scenario titles were changed, however, as follows.

Previous scenario naming convention	Current naming convention
N – Reconstructed Native	Reconstructed Native
H – Historic Gage Data	Recent Past
S1 – Current Operations	Present Operations
S2 – Additional Water Development	Additional Water Development
S3 – Drier Climate	Driest Climate
S5 – Wetter Climate	(no longer used)

Comment 21: Does the absence of significant flood flows in the historical record skew any of the results? The Poudre has not experienced a major flood (100-year or greater) since the early 1900s. Does this pattern affect any of the model results?

Response 21: Yes, it is possible, but the model is limited to the available gage records. There is no way to know if the major floods of the past will occur again or if long-term climate shifts in the watershed are being observed.

Comment 22: The disaggregation of monthly flow data to daily flow does not contain variability. How does the model represent the daily and hourly variability?

Response 22: The disaggregated daily flow is patterned off of the actual daily discharge record of the Canyon Gage; thus, the daily variability of each flow scenario is scaled from the actual flow variability of the river at the Canyon Gage. The best temporal resolution of input to the model is the daily time-step of the input from the Recent Past scenario. It does not represent hourly variability.

NUTRIENTS

Comment 23: Nutrient Control Regulations were passed by the Colorado Water Quality Control Commission on June 11, 2012 so are no longer "proposed" as it reads in the report. Monitoring requirements and continued implementation of the regulations start in March 2013.

> ***Response 23:*** Updated in Section II.

Comment 24: Regarding graphs in an early report, compliance with the regulated nutrient standards will be based on the concentrations of specific nutrient parameters and not loads (kg/year) as depicted in the graphs or TMDL loads as discussed in the text.

> ***Response 24:*** The final text does not indicate the calculated annual loads are the same as the specific nutrient standards.

Comment 25: Biological Nutrient Removal (BNR) processes are already in place and operating at the Mulberry Water Reclamation Facility (MWRF). These processes removed key nutrients: total phosphorus, total inorganic nitrogen, and total nitrogen. A primary goal of that multi-million dollar renovation was to ensure full compliance with the new regulations and treatment processes are being optimized to ensure full compliance. During renovation, discharge to the Poudre stopped in September of 2008. After renovation, discharge to the Poudre began again after Labor Day of 2011. Do the bar graphs depict a "no discharge" condition on the Poudre for the MWRF during that time period as shown by nutrient levels at the Boxelder gage above Boxelder Creek?

> ***Response 25:*** Computations are based upon actual nutrient concentrations from river grab samples, not potential nutrients from waste water contributions.

Comment 26: As required by the Colorado Department of Health, redundant BNR systems have been installed at the Drake Water Reclamation Facility (DWRF), again at a cost of several million dollars to ensure full compliance with the nutrient regulations.

> ***Response 26:*** While this is relevant to the contribution of nutrients from the Fort Collins Wastewater Treatment plant, it does not directly impact the current model.

Comment 27: It should be noted in the text that only the MWRF discharges directly into the Poudre. The DWRF discharges into Fossil Creek Ditch and that, in turn, makes its way some five miles downstream to Fossil Creek Reservoir. The discharge from Fossil Creek Reservoir is to the Poudre is just above the New Cache Irrigation Canal and near where the Poudre crosses below County Road 32E. The reservoir's discharge location is in Segment 12 of the Poudre, downstream of the ERM study area.

> ***Response 27:*** Noted, though outside the scope of this report.

Comment 28: There could be better interaction between hydrology and nutrient processing instead of the current analysis that simply looks at dilution.

> ***Response 28:*** Agreed. The current dilution-based model does not capture the full extent of interaction between nutrients and the compartments of the river system capable of transforming and/or removing them.

AQUATIC

Comment 30: Why is the non-native brown trout species important enough to represent a key indicator? Is not the purpose of this project to evaluate the condition of the natural (native) river ecosystem?

> ***Response 30:*** Cold water fishes are recognized as sensitive indicators of river health regardless of the species. Given that trout were a native component of the fishery at one time, but that native cold water fish declined in large part for reasons other than flows, using brown trout was justified. Brown trout are also recognized as an important part of today's Poudre River because they are a highly valued recreational asset. Native cutthroat trout may be a more natural component of the fish community, but – in their absence – brown trout provide a reasonable surrogate to describe the health of the cold water fish community and there was data available to portray their abundance patterns. Thus, if one portrays brown trout as a surrogate for cold water salmonids in general, and fishes are a major component of the model, inclusion of the Brown Trout indicator is justified.

Comment 31: Is there a model representation of the predatory interaction between the brown trout and native fish? Rainbow trout have a different relationship with native species, as well as unique timing of spawning. Using rainbow trout as the indicator may be beneficial due to the decreased predatory relationship. Using flows that benefit rainbows over brown may have increased improvement for native fisheries.

> ***Response 31:*** Yes, a variable, trout impact on native fishes was included, because at high abundance levels, trout can suppress diversity and abundance of native fishes via predation. Probability values for that metric reflect that even if physical habitat conditions are good for native fishes, a healthy trout population has the ability to suppress native fishes to a relatively low state. Conversely, if physical habitat conditions are good and trout abundance is low, the native fish community (at least the elements that now remain) has a moderate to high probability of achieving a "0" or "+" state.
>
> Rainbows definitely have a different relationship with native fishes than brown trout, but are still predators on other fishes. And yes, they have different needs in terms of spawning success and flows, with rainbow trout being spring spawners. But populations of rainbow trout do not exist in the Poudre River in any numbers; this is mostly due not to flows but to whirling disease. Using cold water species other than brown trout was considered, but – since there is not data to represent them – it seemed an unjustified approach. Brown trout also require spawning gravel for successful reproduction, so some of the same processes that would benefit rainbow trout should also benefit brown trout but in different seasons.
>
> It was also unclear what flow regimes would necessarily benefit rainbow trout over brown trout in this system. Brown trout are mostly negatively affected by higher late-winter and spring scouring flows that reduce survival of early life stages. The Poudre does not seem to have such events in its natural or present, semi-altered state. Even if brown trout were reduced, it is not clear how rainbow trout would benefit given their presently reduced state and apparent lack of reproduction in this system. That may change in the future.
>
> Representing the Poudre River coldwater fish community with rainbow (Hofer hybrid strains) trout rather than brown trout is discussed in part above. It may be that, if reestablishment of rainbow trout is successful, the model could be recalibrated to represent either rainbow or brown trout.

Comment 32: Diversion dams on the Poudre fragment the system and can especially prevent movement by fishes.

> ***Response 32:*** This issue is recognized in the report as an important factor influencing the health of fish populations in highly altered rivers. This is especially true in flow-depleted systems like the Poudre River. However, explicit modeling of fish movement among reaches dissected by diversion dams, as well as a thorough understanding of the effects of dams and restricted movement on distribution and abundance of fishes in an affected reach, are questions for which there are few data in the science literature. This is also especially true for the Poudre River. (See *Response 11*, which discusses spatial model limitations.)

Comment 33: Kurt Davies of Colorado Parks and Wildlife indicated he had more trout data we might want to see to extend the time coverage of our model.

> ***Response 33:*** Unfortunately the data was derived using different methods and slightly different locations, and is therefore difficult to incorporate appropriately.

Comment 34: It was implied that there is better native fish habitat near Interstate 25, but the ERM doesn't include that reach. It would be nice to include this reach.

> ***Response 34:*** The current plan is not to expand the model to more reaches, such as the reach downstream by Interstate 25. Better warm water fish habitat may have existed historically in that area, especially since it is more truly a warm water reach. However, that reach is presently highly confined in channel structure and other attributes, and as a result has less native fish habitat than the reach that was used near the Environmental Learning Center (ELC) property. Inferences about management actions that may enhance native fish habitat could be had by comparing the ELC reach with the one upstream, which is more confined and similar to the Interstate 25 reach.

Comment 35: Impoundments behind dams provide brown trout with suitable habitat in winter when flow conditions are very low.

> ***Response 35:*** Noted. Impoundments do provide habitat for brown trout and other fishes during low flows. They essentially act similar to deep pools in more naturally flowing sections of the river. However, those impoundments are few and are not spatially well-distributed like natural pools in a stream channel. Such pools also collect sediment in low flow periods and do not necessarily support abundant invertebrate communities that support brown trout and other insect-eating fishes.

Comment 36: Someone suggested that new floodplain aquatic habitat would benefit not only native fish but also non-native fish, which might proliferate.

> ***Response 36:*** The ERM team has discussed the issue that any new connections made between ponds and the river would have to be carefully evaluated for the possible undesirable release of new non-natives into the river. Providing habitat is a first step toward supporting more diverse and healthy native fish communities. However, such habitat may support non-native fishes as well, such as western mosquitofish, which compete with and prey upon native fishes that also occur in such habitat. It would also behoove management agencies responsible for mosquito control to

evaluate use of native fishes rather than non-native ones, as the native species are also effective predators on mosquito larvae.

Comment 37: Wood in the channel improves cover for fish, trout and natives.

> ***Response 37:*** This is noted by the team as a positive possible management technique but, as noted in *Comment 3*, it runs against City policy for stormwater management.

RIPARIAN

Comment 38: The definition of *wetland* used in the Riparian Wetland indicator is out of date (14 days of inundation during the growing season; 0.05 exceedance probability). The new USACE definition is 14 consecutive days during the growing season. The report indicates the wetlands target is similar to the regulatory wetlands, but it does not consider the need for the 14 days of inundation to be consecutive.

> ***Response 38:*** The final report will stay consistent with the original previous regulatory definition of wetlands by using the definition of 14 days, not necessarily consecutive per the recent change in Corps regulations. The purpose of the project is not necessarily to be comparable to the very specific, legally binding definitions like that of regulated wetlands. Nevertheless, by using the previous version it will serve as a parallel or proxy.

Comment 39: Could groundwater be incorporated into the model? Return flow could be an alternative source of water for the riparian forest and wetlands.

> ***Response 39:*** Groundwater could have been incorporated into these models if there were sufficient data. Individual wells tell little about the direction of movement and the slopes of groundwater surfaces; they offer a depth to the water table at a point in time. Return flow could be an important source of water for riparian forest in this type of environment where much water is used in agriculture and landscaping in the urban environment, however it is not a constant or predictable pattern. The ERM was built on the excepted assumption that groundwater and surface water fluctuate together in the near channel areas of the Poudre (particularly those that are within the area flooded by a flow of 7000 cfs).

Comment 40: Another valuable response variable, in addition to Riparian Wetlands and Rejuvenating Mosaic, is the relict forest (the old deciduous forest that persists via access to groundwater).

> ***Response 40:*** It is recognized that the extant mature riparian forests rely on groundwater, and may in fact be more responsive to lateral sources of groundwater independent of water supplied by instream flow along the Poudre. In addition, these forests are well established and likely to persist even after conditions shift away from optimal for the trees. This is why realized niche modeling was performed, the output of which is probabilistic. Based upon where a particular species or cover type is now, this is the most probable outcome if conditions change. Such outcomes vary based upon the resistance and resilience of the species/cover types in question and other factors (grazing, vegetation removal, floods, droughts, etc.).

Comment 41: The desirable forest species (native cottonwood versus non-native maple or green ash) is a social question rather than a scientific one.

Response 41: Indeed, many non-native species also provide habitat (cover, food, shade, nest sites, etc.). Cottonwood per se was not singled out as the only riparian forest species. Several non-native species were included in our models.

Comment 42: How does laying banks back (removing constraints) and widening a channel affect critical shear stress? Could laying banks back for “restoration” conflict with aquatic habitat maintenance?

Response 42: Certainly a wider and shallower channel will result in more flow to achieve the shear stress necessary to mobilize the bed. This could result in more fine sediment in the interstitial spaces and habitat degradation in the channel.

Comment 43: How would the loss of willow cover (as per riparian probabilistic models under drying scenarios) affect bank stability? Could the loss of willow under dry scenarios result in a wide, shallow, active channel?

Response 43: Yes, if willow and other woody species were removed or lost due to drought, there could be bank erosion and channel widening in areas that are not riprapped.

Comment 44: Wetland and dynamic mosaic occurs primarily in narrow zones near the channel within riprap. These areas could be better managed and widened within confined zones or if the zone were expanded.

Response 44: Certainly, and this is a good thought. In- and near-channel wetlands could be expanded through removal of constraints such as riprap and abutments, bike paths, roads, etc. Laying back channel margins, creating a topographic gradient, and then managing flows to support desired vegetation types would be ecologically important.

Comment 45: Why focus only on flow and current geometry? The ERM should consider channel movement, restoration, and reforming topography.

Response 45: By evaluating three different reaches with distinct geometry and flow combinations, it was possible to cross compare the benefits and limitations of various degrees of channel constraint, topographies, and channel forms.

Comment 46: What is a “good” value for a Hosmer-Lemeshow p-value? Both models purportedly had excellent fit, but – to the untrained eye – 0.7 and 0.14 are very different values.

Response 46: Clarification will be added to the report. The null hypothesis being tested in the Hosmer-Lemeshow goodness of fit test is that the model fits the data well. Higher p-values (>0.05) do not allow this hypothesis to be rejected, thus indicating a good model fit.

Comment 47: Much of the riparian zone area is inundated via groundwater during the high flow stage, but the model is based only on surface flows. Why is depth to groundwater not a component in the model? What could be a good proxy for groundwater flow?

Response 47: Addressed above. Also, there is a strong relationship between surface water level (stage) and groundwater levels along streams, though these relationships change over the course of a seasonal hydrograph. Precise information about groundwater levels relative to each of the vegetation plots would have enabled the incorporation of such information into the model, but such data was not available. Because elevation above the channel is often highly inversely correlated with water availability, and is highly correlated to depth of water table, this was used as the master variable. This indeed explained a significant proportion of the variability in plant community composition and the presence or absence of certain species and cover types.

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