Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Riparian Instream Flow (Study 8.6) and Fluvial Geomorphology (Study 6.6)

Dam Effects on Downstream Channel and Floodplain Geomorphology and Riparian Plant Communities and Ecosystems– Literature Review
Technical Memorandum

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

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TABLE OF CONTENTS

LIST OF FIGURES

APPENDICES

LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
AEA	Alaska Energy Authority
ARIS	Adaptive Resolution Imaging Sonar
°C	Degrees centigrade
cfs	Cubic feet per second
cm	Centimeter
CPOM	Coarse Particulate Organic Material
FA	Focus Area
FDA	Fish Distribution and Abundance
FERC	Federal Energy Regulatory Commission
FPOM	Fine Particulate Organic Material
fps	Feet per second
mg/L	Milligrams per liter
HSC	Habitat Suitability Criteria
HSI	Habitat Suitability Indices
IFS	Instream Flow Study
ISR	Initial Study Report
km	Kilometer
MW	Megawatts
NTU	Nephelometric Turbidity Units
PRM	Project River Mile
PTF	Pulse-type Flows
RSP	Revised Study Plan
TM	Technical Memorandum

EXECUTIVE SUMMARY

The *Dam Effects on Downstream Channel and Floodplain Geomorphology and Riparian Plant Communities and Ecosystems−Literature Review Technical Memorandum* is a study element of the comprehensive Alaska Energy Authority (AEA) Revised Study Plan (RSP) submitted to the Federal Energy Regulatory Commission (FERC) on December 14, 2012. This technical memorandum combines the Riparian IFS (Study 8.6) and Geomorphology Studies (Studies 6.5 and 6.6) reviews of the scientific literature concerning downstream effects of dams. The goal of the Riparian Instream Flow Study is to provide a quantitative, spatially-explicit model to predict potential impacts to downstream floodplain vegetation from Project operational flow modification of natural Susitna River flow, sediment, and ice process regimes (RSP Section 8.6). The goal of the Geomorphology Study is to characterize the geomorphology of the Susitna River, and to evaluate the effects of the Project on the geomorphology and dynamics of the river by predicting the trend and magnitude of geomorphic response (RSP Section 6.5). The objective of this Technical Memorandum is to synthesize studies of hydro project impacts on downstream floodplain plant communities, studies of un-impacted floodplain plant community successional processes, and historic physical and biologic data for the Susitna River floodplain vegetation, including 1980s studies (RSP Section 8.6.3.1). As such, this literature review summarizes reported study results and findings, presented as general background information, to inform potential responses of the Susitna River channel, floodplain and riparian ecosystem to Susitna-Watana Hydro Project operational flow modifications. The ability to explicitly predict likely responses to the Project based on the results of other studies of dam impacts, especially within the boreal zone, is hampered by the singularity (sensu Schumm 1991) of all river systems. Thus, the Riparian IFS (Study 8.6) and Geomorphology Studies (Studies 6.5 and 6.6) are designed to assess specific potential Project downstream impacts to Susitna River geomorphology, riparian vegetation and riparian ecosystems.

The literature review is presented in three sections: (1) introduction, including nature and scope of the question, theoretical framework, riverine─riparian ecosystems, and definition of dams and hydroregulation; (2) review of 1980s Susitna River riparian studies; and (3) review of literature concerning dam effects on downstream channel and floodplain geomorphology and riparian plant communities and ecosystems. An annotated, searchable bibliography is provided in Appendix A.

Dams affect the primary factors that determine the shape, size and overall morphology of a river and its floodplain, the hydrologic regime (magnitude, frequency and duration of flows) and sediment supply (volume and size) and the frequency of sediment transport (Schumm 1977). In spite of decades of investigation of the effects of dams on downstream rivers (Petts 1979, 1980; Williams and Wolman 1984; Ligon et al. 1995; Friedman et al. 1998; Graf 1999, 2006; Webb et al. 1999; Petts and Gurnell 2005; Magilligan and Nislow 2005; Fitzhugh and Vogel 2011; Marren et al. 2014), there are few general models that predict how any particular river is likely to respond once a dam is emplaced (Grant et al. 2003). More often than not, the results of case studies have tended to highlight variation in response rather than consistency (Williams and Wolman 1984; Friedman et al. 1998; Ligon et al. 1995; Grant et al. 2003; Fassnacht et al. 2003; Vadnais et al. 2012). The reported range of downstream geomorphic responses below dams include channel degradation or aggradation, channel narrowing or widening, bed material

coarsening or fining, planform change, change of gradient, tributary degradation or progradation, as well as changes to floodplain connectivity and morphology (Kellerhals and Gill 1973; Petts 1980; Williams 1978; Williams and Wolman 1984; Carling 1988; Lagasse 1980: Germanoski and Ritter 1988; Church 1995; Brandt 2000; Grams and Schmidt 2002; Svendsen et al. 2009; Marren et al. 2014). There are also reported instances where dams have had very little or no effect on channel morphology (Williams and Wolman 1984; Inbar 1990; Fassnacht et al. 2003; Vadnais et al. 2012). Much of the reported variation in the physical response of the rivers downstream of dams is probably due to the location of the dam within the watershed (Marren et al. 2014). The closer the dam is to the head of the watershed, the more likely the response to the dam will tend to be muted by other factors such as the presence bedrock, large diameter deposits derived from historical hillslope failures, extreme magnitude paleofloods, debris flows or glacial or fluvioglacial processes. In addition, intrinsically very low sediment transport rates, the result of either low sediment supply or low transport capacities, under pre-dam conditions will also tend to mute the impact of the dam. Consequently the geological setting and geological history of the dam-affected reaches and not just the changes in hydrology and sediment flux must be factored into the below-dam assessment (Swanson et al. 1985; Webb et al. 1999; Grant et al. 2003; Fassnacht et al. 2003; Curran and O'Connor 2003; O'Connor et al. 2003; Vadnais et al. 2012). Additionally, the time necessary for response to dam emplacement and operation depends upon dam operations scenarios and ranges from months to millennia, and the direction of the response may change over time (Petts 1979, 1980; Williams and Wolman 1984; Friedman et al. 1998; Church 1995; Gaeuman et al. 2005; Church 2015).

The downstream extent and magnitude of the altered flow regime depends on tributary inflows and whether the tributaries are themselves also regulated (Williams and Wolman 1984; Magilligan and Nislow 2005; Graf 2006; Fitzhugh and Vogel 2011). The time necessary for response to dam emplacement and operation ranges from months to millennia, and the direction of the response may change over time (Petts 1979, 1980; Williams and Wolman 1984; Friedman et al. 1998; Church 1995; Gaeuman et al. 2005; Church 2015).

In boreal rivers, dams also affect the timing, duration and locations of ice formation as well as ice thickness and ice freeze-up and breakup characteristics (Prowse and Conly 2002; Prowse et al. 2002; Prowse and Culp 2003; Beltaos and Burrell 2002; Church 2015). These in turn affect the magnitude and frequency of flood stages (that always exceed those of open-water floods), short duration ice jam surges and runs and sediment transport within the channel as well as overbank sedimentation and erosion (Smith 1980; Smith and Pearce 2001; Ettema and Daly 2004; Ettema 2008). Under regulated flow conditions, ice-jam flooding provides the primary means of supplying sediment to the floodplain, but because ice jams tend to form at specific locations (Smith 1980; Uunila 1997; Smith and Pearce 2001) the effects tend to be localized. Ice jams remain the dominant form of physical disturbance but freeze-up jams tend to dominate nearest the dam and break-up jams farther downstream (Uunila and Church 2015). The impacts of dams on ice processes and consequently on floodplain erosion and deposition are unclear and likely depend on the operation of the dam and its effects on the ice dynamics as well as the effects of the dam on the supply of finer sediments that form the bulk of the floodplain (Church 1995). Flow management to control downstream ice effects have included releases of higher flows in the freeze-up period to encourage ice formation at higher elevations and reduced flows in the break up period (Uunila and Church 2015).

Dams in their alteration of natural flow and disturbance regimes have been shown to alter downstream floodplain vegetation mosaic composition, structure and function (Rood et al. 2005; Johnson et al. 2012; Scott et al. 1996; Shafroth et al. 2010; Jansson et al. 2000a; Naiman et al. 2005). Although the review results are focused on northern temperate and boreal river systems such as the Susitna River, central Alaska, most dam effects research to-date has been conducted on rivers located in temperate, semi-arid and arid climates with a notable exception of detailed studies of dam effects on the Peace River, northern Alberta, Canada (Church 2015). Dam effects literature is reviewed as a whole, summarizing the general findings and the applicability of the results to northern temperate and boreal riverine–riparian ecosystems. The effects of dam hydroregulation have been demonstrated to result in a cascade of effects through the riverine–riparian ecosystem affecting first, the riparian vegetation mosaic pattern, and secondly, riparian and aquatic fish and wildlife populations (Naiman et al. 2000; Nilsson and Berggren 2000). The “cascade of effects” of dams throughout the riverine–riparian ecosystem, and the complex alteration of downstream aquatic and riparian communities, has been noted by a number of authors (Ward and Stanford 1983; Ligon et al. 1995; Richter et al. 1996; Poff et al. 1997; Naiman et al. 2000; Nilsson and Berggren 2000; Rood et al. 2005; Tockner and Stanford 2002; Naiman et al. 2005; Jorde et al. 2008). Downstream dam effects are dependent upon the type of dam operations scenarios, river network dam location, and influence of downstream tributary flow and sediment contributions.

Both existing patterns and predicted changes in the dynamics of vegetation under the flow regime presented by the Susitna hydroelectric proposals of the early 1980s were described in a number of reports of that era (Helm and Collins 1997; Riparian Vegetation Succession Report 1985 [UAFAFES 1985]; Impacts Assessment Downstream Vegetation 1986 [Harza-Ebasco 1986]). The authors of those reports assessed the relative importance of flooding, ice, wind and wildlife interactions in establishing and maintaining the vegetation patterns present across the Susitna River floodplain. Together with observations of various disturbances to these successional pathways, the 1980s authors created a general conceptual model to describe the dynamics of the Susitna River floodplain and to predict impacts of the multi-stage, two-dam project under consideration at that time.

In review, dam impacts to channel and floodplain geomorphic processes have been characterized by Marren et al. (2014) as both passive and active in nature. In passive impacts the floodplain becomes an inactive alluvial surface relative to overbank flooding and associated sediment depositional processes. Floodplain ecological processes dependent upon flood and sediment regimes are altered changing the trajectory of riparian plant community succession and ecological functions associated with those communities. Active impacts, changes in the sediment:water ratio, result in changes in channel and floodplain forming geomorphic processes altering the type and character of floodplain surfaces available for vegetation establishment.

The effects of river ice processes on riparian vegetation in northern temperate and boreal rivers has received little study world-wide (Prowse and Beltaos 2002; Engstrom et al. 2011; Lind et al. 2014; Uunila and Church 2015). Research to-date reports that river ice jam formation and break-up results in two primary types of vegetation disturbance: (1) mechanical shearing of vegetation from ice rafts transported along the channel edge and onto the floodplain surface, and (2) burial of existing plant communities by overbank deposition of entrained sediment (Uunila and Church 2015; Engstrom et al. 2011; Boucher et al. 2009). In northern temperate and boreal rivers ice process effects, in addition to open water fluvial processes, play an underreported yet potentially significant role in generation of floodplain forest composition, structure and distribution.

An impact to floodplain plant communities reported nearly universally in the dam effects literature is the invasion of exotic plant species into hydrodynamically altered riparian zones (Johnson et al. 2012; Braatne et al. 2007; Richards et al. 2002; Nilsson and Berggren 2000; De Waal 1994). The alteration of natural flow and disturbance regimes creates new physical habitat conditions─channel and floodplain physical surfaces with altered hydrologic gradients, sediment conditions and hydrogeomorphic regimes─that favor invasive exotic plant species life history adaptations over historic native riparian vegetation (Braatne et al. 2007; Lytle and Poff 2004; Nilsson and Berggren 2000).

1. INTRODUCTION

The goal of the Riparian Instream Flow Study is to provide a quantitative, spatially-explicit model to predict potential impacts to downstream floodplain vegetation from Project operational flow modification of natural Susitna River flow, sediment, and ice process regimes (RSP Section 8.6). The goal of the Geomorphology Study is to characterize the geomorphology of the Susitna River, and to evaluate the effects of the Project on the geomorphology and dynamics of the river by predicting the trend and magnitude of geomorphic response (RSP Section 6.5). The objective of this Technical Memorandum is to synthesize historic physical and biologic data for the Susitna River floodplain vegetation, including 1980s studies, studies of hydro project impacts on downstream floodplain plant communities and studies of un-impacted floodplain plant community successional processes (RSP Section 8.6.3.1). As such, the objective of this scientific and engineering literature review is to summarize reported study results and findings and to present them as general background information to inform the most likely responses of the river channel, floodplain and riparian ecosystem to Project operational flow modifications. The ability to explicitly predict likely responses to the Project based on the results of other studies of dam impacts, especially within the boreal zone, is hampered by the singularity (sensu Schumm 1991) of all river systems. Thus, the Riparian IFS and Geomorphology Studies are designed to assess specific potential Project downstream impacts to Susitna River geomorphology, riparian vegetation and riparian ecosystems.

1.1. Nature and Scope of the Question

Natural flow, sediment and ice regimes; geologic setting; and climate are primary controls of channel and floodplain development and riparian vegetation pattern in northern temperate and boreal river networks (Rood et al. 2007; Naiman et al. 1998; Naiman et al. 2005). The interactions among climate, geology, physical process regimes and channel / floodplain planform create physical templates and hydrologic and disturbance gradients that control the characteristic patchiness or mosaic pattern observed in active river valleys (Montgomery 1999; Fetherston et al. 1995; Naiman et al. 1998). Floodplain, or riparian vegetation pattern, has been described as a forest floodplain mosaic (Fetherston et al. 1995), dynamic patch mosaic (Latterell et al. 2006), and shifting habitat mosaic (Arscott et al. 2002; Malard et al. 2002; Stanford et al. 2005). All of these descriptions reflect the observation that natural flow, sediment and ice processes annually disturb existing floodplains and floodplain vegetation creating a mosaic of vegetation patches whose origin dates back to the primary disturbance event and the temporal state of floodplain vegetation succession. Once established on newly deposited or eroded floodplain surfaces, riparian vegetation develops through regionally and watershed characteristic plant community successional stages strongly influenced by gradients of water availability (Naiman et al. 1998; Merritt et al. 2009).

The term disturbance, as used here in the riverine─riparian context, refers to hydrogeomorphic, and atmospheric processes, that alter riparian habitats and ecosystem processes thereby affecting riparian plant community age, composition, distribution, structure and ecosystem function (Montgomery 1999; Naiman et al. 2005). Riparian disturbances include: erosion and sediment deposition resulting from both open water and ice jam mediated backwater flooding; ice mechanical shearing; wind throw; and fire (Naiman et al. 1998; Rood et al. 2005).

Riparian and riverine aquatic plant species have evolved under, and are adapted to, natural flow and disturbance regimes (Merritt et al. 2009; Lytle and Poff 2004; Poff et al. 1997; Naiman et al. 1998). Riparian plant species life history strategies−including morphological, phenological, and physiological traits−are unique to specific climatic and natural flow and disturbance regimes. As such, many riparian plant species, and riparian plant communities, are dependent upon the natural riverine flow and disturbance regimes for dispersal, survival and reproduction (Merritt et al. 2009; Lytle and Poff 2004).

In river valleys, riparian vegetation mosaic supports a wide diversity of riverine and riparian physical, biogeochemical and fish and wildlife habitat functions. Riparian support functions include: terrestrial wildlife habitat structure, wildlife food resources, aquatic nutrient and energy subsidies, and biogeomorphic stabilization of floodplains and river banks (Merritt et al. 2009).

Dams in their alteration of natural flow and disturbance regimes have been shown to effect downstream riparian vegetation mosaic composition, structure and function (Rood et al. 2005; Johnson et al. 2012; Scott et al. 1996; Shafroth et al. 2010; Jansson et al. 2000a; Naiman et al. 2005). The effects of dam hydroregulation have been demonstrated to result in a cascade of effects through the riverine─riparian ecosystem effecting first, the riparian vegetation mosaic pattern, and secondly, riparian and aquatic fish and wildlife populations (Naiman et al. 2000; Nilsson and Berggren 2000). Richards et al. (2002) describe the cascade of dam effects and their cumulative impact in riverine─riparian landscapes:

"River hydroregulation by dams results in a terrestrialization of the vegetation, associated with a reduced rate of turnover of the fluvial landscape, reduced rates of ecosystem change, reduction of channel and ecosystem dynamics and of mosaic detail, reduced flood frequency, and loss of habitat and age diversity."

This literature review examines downstream impacts of dams on channel and floodplain geomorphology and floodplain plant communities and ecosystems. Although the review results are focused on northern temperate and boreal river systems such as the Susitna River, central Alaska, most dam effects research to-date has been conducted on rivers located in temperate, semi-arid and arid climates with a notable exception of the detailed studies of dam effects on the Peace River, northern Alberta, Canada (Church 2015). Therefore the literature was reviewed as a whole, general findings are summarized and the applicability of the results to northern temperate and boreal riverine─riparian ecosystems are discussed.

The review is presented in the following sections: (1) introduction, including nature and scope of the question, theoretical framework, riverine and riparian ecosystems, and definition of dams and hydroregulation; (2) review of 1980s Susitna River riparian studies; and (3) dam effects literature review with sections on first, second, third and fourth order impacts. An annotated, searchable bibliography is provided in Appendix A. Given the broad topic of dam effects, and the range of disciplines that have studied such effects, the bibliography has been designed to be a living document that will be updated throughout the life of the Susitna-Watana Hydroelectric Project as new literature is identified.

1.2. Process-based, Hierarchical Framework for Assessing Riverine-Floodplain Ecosystem Impacts of Dam Operations

The literature review results and discussion are presented in a process-based, hierarchical framework designed for assessing riverine−floodplain ecosystem effects of dam operations over space and time. The conceptual framework is based on a fluvial-centric systems model initially proposed by Petts (1984) and subsequently modified by Jorde et al. (2008) and Burke et al. (2009) (Figure 1). The framework of the literature review allows for clear assessment of: (1) physical and biological process linkages at a range of spatial and temporal scales, and (2) cascading effects of dams from first order physical drivers to second and third order geomorphic and ecological responses to finally fourth order biogeomorphic feedback processes. Due to the significant effects of ice processes on northern temperate and boreal river dynamics and morphology (Smith 1979; Smith 1980; Church 1995; Beltaos and Burrell 2002; Ettema 2008; Church 2015), the Burke et al. (2009) model was modified by adding Ice Processes as a First Order impact that has cascading effects on floodplain and channel morphology, in-channel and overbank hydraulics, in-channel and overbank sediment transport and deposition (Second Order impacts) and riparian vegetation distribution and succession (Third Order impacts) (Figure 1). The hierarchical levels are defined as follows (after Petts 1984; Burke et al. 2009):

1.2.1. First-order Impacts

First-order impacts are changes to primary physical drivers of the fluvial system: hydrology, sediment supply, water quality, and ice processes (Williams and Wolman 1984; Richter et al. 1996; Poff et al. 1997; Naiman et al. 2000; Grant et al. 2003; Church 2015). Changes in first-order processes lead to second-order effects.

1.2.2. Second-order Impacts

Second-order impacts result from changes in hydrology, sediment supply and ice processes. They include altered hydraulics, sediment transport, ice process dynamics and channel and floodplain morphology (Williams and Wolman 1984; Church 1995; Grant et al. 2003; Marren et al. 2014; Church 2015).

1.2.3. Third-order Impacts

Third-order impacts are the ecological response of biological communities and ecosystems, through direct and indirect linkages, to both first- and second-order impacts (Ligon et al. 1995; Jorde and Bratrich 1998; Naiman et al. 2000; Rood et al. 2005; Merritt et al. 2009). Third-order impacts are ecological responses to altered physical habitat template.

1.2.4. Fourth-order Impacts

Fourth-order impacts describe biogeomorphic feedback between ecological responses and physical processes (Naiman et al. 2000; Rood et al. 2005).

Together, the effects of dams on downstream riverine─riparian ecosystems can be seen as a cascade of impacts from first to second to third to fourth order, with fourth order biogeomorphic feedbacks to second and third order impacts (Figure 1). The “cascade of effects” of dams throughout the riverine─riparian ecosystem, and the complex alteration of downstream aquatic and riparian species composition, structure and function, has been noted by a number of authors (Ward and Stanford 1983; Ligon et al. 1995; Richter et al. 1996; Poff et al. 1997; Naiman et al. 2000, 2005; Nilsson and Berggren 2000; Rood et al. 2005; Tockner and Stanford 2002; Jorde et al. 2008).

1.3. Riverine-Riparian Ecosystems

To review the literature on the effects of dams on downstream riverine─riparian ecosystems it is useful to have an ecological framework that integrates hydrogeomorphic and ecological processes. Four ecological paradigms are presented as background for the review: (1) natural flow regime (Poff et al. 1997), (2) natural disturbance regime (Rood et al. 2007), (3) shifting habitat mosaic (Stanford et al. 2005), and (4) riparian species life history characters and adaptations.

1.3.1. The Natural Flow Regime: Surface Water and Groundwater

Riparian vegetation has evolved adaptations to disperse, establish, survive and reproduce in response to specific elements of a river’s natural flow regime (Poff et al. 1997) including: seasonal timing, frequency, magnitude, duration and predictability (Mahoney and Rood 1998; Merritt et al. 2009; Lytle and Poff 2004). As a result of these adaptations there are strong linkages between riparian plant community life history traits, riparian plant community composition and a river’s natural flow regime (Merritt et al. 2009). In riverine─riparian ecosystems, gradients of water availability and fluvial disturbances control plant community organization and pattern (Merritt et al. 2009).

Identification of hydroregime requirements for individual riparian plant species from the germinant-seedling establishment stage to stages of reproduction and senescence is understood for very few riparian species (Merritt et al. 2009). The most studied riparian species are the cottonwoods (*Populus* spp.) and species specific recruitment models have been developed and used for designing environmental flow regimes supportive of cottonwood establishment in hydroregulated rivers (Mahoney and Rood 1998; Braatne et al. 1996).

Mountain rivers in the temperate and boreal regions of the Northern Hemisphere are characterized by seasonal flow pattern with annual spring to early summer snowmelt driven peak flows (Rood et al. 2007; Mahoney and Rood 1998; Naiman et al. 2005) followed by an abrupt decrease in discharge and slowly falling limb of the hydrograph. The timing, magnitude, duration and frequency of these floods has been demonstrated to be a critical ecological process controlling the characteristic patterns of riparian plant communities and ecosystem processes (Junk et al. 1989; Hughes 1990; Scott et al. 1996; Naiman et al. 2005).

Once riparian plants are established access to groundwater may become a limiting factor determining successful growth to maturity and reproductive stage (Lite and Stromberg 2005; Rood et al. 2003). Climatic gradients of available precipitation very significantly from arid to temperate and boreal regions playing a significant role in determining the vulnerability of riparian vegetation to drought stress (Cooper et al. 1999; Rood et al. 2003; Henszey et al. 2004). Floodplain groundwater depths, in arid to semi-arid regions, have been demonstrated to control individual plant species rooting depths and floodplain plant community composition, species richness, and structure (Rood et al. 2011; Henszey et al. 2004; Baird et al. 2005).

1.3.2. The Natural Disturbance Regime

Riparian vegetation composition, abundance and spatial distribution throughout the river valley bottom is a direct response to natural flow, sediment and ice process disturbance regimes that control the formation of the channel and floodplain habitat template upon which riparian vegetation establishes and later develops to maturity through forest successional processes. Riparian vegetation channel and floodplain habitat conditions control the characteristic floodplain forest mosaic pattern. In the conclusion of a review of literature concerning the disturbance regime of North American riparian cottonwoods Rood et al. (2007) recommended adoption of the term “natural disturbance regime,” as a complement to “natural flow regime” which is recognized as a primary organizing paradigm in river ecology, for characterizing physical processes that control floodplain vegetation pattern. In ecological literature the term disturbance is defined as a process that disrupts ecosystem processes (Sousa 1984; Pickett and White 1985; Naiman et al. 2005). A natural disturbance regime may be characterized by the disturbance types and their timing, frequency, magnitude and duration. Hydrogeomorphic (erosion and sediment deposition) and river ice effects (mechanical shearing, erosion and sediment deposition) are together the primary riparian disturbance processes operating in northern temperate and boreal rivers (Naiman et al. 1998; Rood et al. 2007).

1.3.3. Shifting Habitat Mosaic: Floodplain Vegetation Mosaic of Successional Stages

Floodplain vegetation pattern, has been described as a forest floodplain mosaic (Fetherston et al. 1995), dynamic patch mosaic (Latterell et al. 2006), and shifting habitat mosaic (Arscott et al. 2002; Malard et al. 2002; Stanford et al. 2005); all of these descriptions reflect the observation that natural flow, sediment and ice processes annually disturb existing floodplains and floodplain vegetation creating a mosaic of vegetation patches whose origin dates back to the primary disturbance event and the temporal state of floodplain vegetation succession. Once established on newly deposited or eroded floodplain surfaces, riparian vegetation develops through regionally and watershed characteristic plant community successional stages strongly influenced by gradients of water availability (Naiman et al. 1998; Merritt et al. 2009). The floodplain mosaic pattern is generated and maintained by river network specific disturbance regimes that vary systematically through a river network (Montgomery 1999). Dam effects that alter the natural disturbance regime of a river will result in alterations of the characteristic riparian vegetation mosaic pattern (Johnson 1994).

1.3.4. Riparian Species Life History Adaptations to Natural Flow and Disturbance Regimes

"Riparian vegetation composition, structure and abundance are governed to a large degree by river flow regime and flow-mediated fluvial processes. Streamflow regime exerts selective pressures on riparian vegetation, resulting in adaptations (trait syndromes) to specific flow attributes." (Merritt et al. 2009)

Riparian and aquatic species have evolved life history strategies primarily in direct response to the natural flow, sediment and ice process regimes (Lytle and Poff 2004; Merritt et al. 2009). Plant life history strategies of the family *Salicaceae*, cottonwoods and willows, are synchronized with long-term flow, sediment and ice disturbance patterns (Rood et al. 2007). In North American watersheds with snow-melt driven spring peak flows Salicaceae species have evolved watershed specific seed dispersal timing that is synchronized with spring snow melt peak flows and the descending hydrograph limb (Stella et al. 2006). The synchrony of cottonwood seed release is driven by a threshold of cumulative atmospheric heat load, and concordant snow melt driven peak flows. This process illustrates the evolutionary adaptation of these species within specific watersheds (Stella et al. 2006; Braatne et al. 1996). Cottonwood species release seed earlier in New Mexico than Alberta and central Alaska controlled by earlier spring temperatures. Dam changes to the temporal and spatial pattern of natural flow, sediment and ice process regimes have been shown to have direct and indirect effects upon aquatic and riparian species viability (Bunn and Arthington 2002).

1.4. Dams and Hydroregulation Defined

Section 1.4 is taken largely from materials presented in Reiser et al. 2005 as provided in the River Productivity Technical Memorandum, Review of the Effects of Hydropower on Factors Controlling Benthic Communities (R2 2014) and has been modified for purposes of this review to include a discussion of environmental flow releases (Section 1.4.1.4). This section is included within this Technical Memorandum for completeness and for the reader's convenience.

1.4.1. Hydropower Flow Operations

A regulated river is one in which the natural flow regime has been purposely altered or controlled, generally via construction of a dam, to meet an anthropogenic purpose, whether it be for flood control, water supply, or hydroelectric generation. The effects of these types of projects on downstream ecosystems can range widely depending on operational flow regimes, and geographic and climatic setting. This section will focus on a specific class of operational effects that are most often associated with hydroelectric operations, pulse-type flows (PTF) (Poff et al. 1997). The effect of pulse-type flows are related to the sharp and sudden increase in flows (e.g., pulse) for a relatively short period of time and then a decrease back to the original flow. These types of flow patterns may be related to power operations as well as to meet specific resource objectives, such as for fish and recreational purposes. The sections that follow will describe the more common PTF operations used in hydropower.

1.4.2. Pulse-Type Flows

Pulse-type flows (PTF) can occur in response to power generation needs as well as to meet specific resource objectives such as provision of recreation flows, flushing flows, attraction flows, environmental flows and others. Given that the patterns of flow releases below projects can differ dramatically, the resulting effects on downstream ecosystems will differ as well. In this section, the most common types of PTF that are associated with hydroelectric projects are described. In this discussion, the term "baseflow" is used to refer to the flow that occurs just prior to and after the PTF cycle rather than the low flow condition that typically represents the groundwater contribution to a river system.

1.4.2.1. Power Peaking Flows

Hydroelectric projects that operate as peaking facilities are designed to meet increased demands for power during certain periods of the day and reduced demands at other times. Peaking operations typically result in daily cycles of increasing flows during morning hours to some level sufficient to meet demand, sustained flow at that level for a certain period of time, followed by a reduction in flow as demand goes down. This power peaking pattern often only occurs during the weekdays; reduced power demand on weekends relegates operations to more of a baseload condition in which flows remain steady (Figure 2). The overall magnitude of flow change between the baseflow and peak flow can be quite large and can result in stage differences on the order of feet for some projects. These short-term flow fluctuations result in the repeated dewatering and re-inundation of those shoreline areas and the fluctuating current velocities over submerged substrates, creating a "freshwater intertidal zone," also called the varial zone (Figure 3), which is characterized by reduced invertebrate density and diversity, as well as low algal production. As flows ramp up and down, there are generally few regulations on the rate of flow change during the up-ramp cycle (exceptions generally related to safety considerations associated with angling, recreation, etc.), but the rate of flow reduction (down-ramp) is often specified as part of project operations.

1.4.2.2. Load-Following Flows

Another type of PTF that is related to increased power demands are flows associated with "Load-following." Load-following can result in real-time changes in flow releases to match real-time shifts in power demand; in essence, flows are regulated to match increasing or decreasing power loads that can occur throughout a 24 hour period. Oftentimes, load-following is integrated directly into a peaking operation, but they can be separate depending on FERC license conditions for a given facility. Load-following can result in large fluctuations in flow over relatively short time intervals. Multiple cycles can occur within a day, for example, as seen in historical operations of the Kerr Dam on the Flathead River, Montana (Figure 2), or load-following effects of the Baker Project on the lower Skagit River, Washington (Figure 4). Load following effects depicted as sharp increases-decreases in flow are evident at other times in Figure 2 and are associated with the daily peaking cycle.

In general, the same categories of impacts as noted above for peaking flows can occur with load-following operations; i.e., varial zone formation delineated by the upper and lower flow cycle (Figure 3). Given the frequency and magnitude of fluctuations, impacts may actually be greater under load-following than under straight peaking operations. Similar to peaking, load-following operations are typically not restricted in how fast flows can be increased, but are often regulated as to how quickly they can be reduced.

1.4.2.3. Flushing Flows and Channel Maintenance Flows

Another category of PTF is the programmed release of flows designed to mobilize and transport sediments from stream segments below a dam, often called "flushing flows," or to maintain channel form and function, termed "channel maintenance flows." Both can result in a rapid increase in flows up to a predetermined level where they are maintained for a specified period of time (determined sufficient to achieve sediment transport objectives – typically 1-7 days), and then are reduced to baseflow conditions. The magnitude, duration and frequency of these types of PTF are highly dependent on resource management objectives, ambient sediment conditions, and project specific operations (Reiser et al. 1989; Kondolf and Wilcock 1996).

Graphically, a flushing flow is similar in pattern to a peaking cycle that would remain at the high flow for several days before decreasing (Figure 5). The frequency of these kinds of PTF is much less than peaking flows; once per year or less is generally sufficient unless a catastrophic input of sediment occurs requiring additional prescriptive flows. The release of a flushing flow or channel maintenance flow is typically timed to be synchronous with normal runoff processes so its effects are ecologically compatible and beneficial to the existing aquatic biota. However, different release timings may be needed to offset catastrophic sediment influx.

Depending on the management objectives, the magnitude of these types of flows can range from large (sufficient to mobilize the bed and flush sediments at depth) to moderate (sufficient to mobilize surficial fine sediments). However, the duration and frequency of these types of PTF are generally short (1-7 days, 1 time per year); any effects to biota can likely be reduced if the rate of flow reduction (downramping) is low. The short-term cycle of a programmed flushing flow or channel maintenance flow release does not allow the formation of a defined varial zone.

1.4.2.4. Environmental Flows

Alteration of natural flow regimes due to dam operation may result in significant impacts to downstream aquatic and riparian communities and ecosystems (for general reviews see Ward and Stanford 1995; Nilsson and Berggren 2000; Nilsson and Svedmark 2002). Recently, land and water resource programs have been developed to mitigate dam downstream impacts such as the Sustainable Rivers Project developed by the Nature Conservancy in collaboration with the U.S. Army Corps of Engineers (Richter et al. 2006). The aim of these programs is to develop integrated ecological flow regimes for existing dam facilities that restore and protect the health of rivers and riparian ecosystems while continuing to provide human services such as flood control and electric power generation (Shafroth and Beauchamp 2006). The environmental flow program developed for the Bill Williams River, Arizona, Alamo Dam is an ecologically comprehensive flow release regime determined by assessment of flow requirements for suite of aquatic and riparian biota: riparian vegetation, birds, fishes, aquatic macro-invertebrates, amphibians and riparian terrestrial fauna. For each group of species baseflow and floodflow requirements were specified (Shafroth and Beauchamp 2006). The Sustainable Rivers Project has also evaluated environmental flows programs for the Savannah River, Georgia and Mokelumne River, California (http://www.nature.org/ourinitiatives/habitats/riverslakes/sustainable-rivers-project.xml).

1.4.2.5. Recreation Pulse Flows

Flows for recreation-based activities such as rafting, kayaking, boating, fishing, etc. represent another kind of PTF. These types of flows can range widely in their magnitude, frequency, and duration, depending on project layout and operational constraints. For some projects, recreation flows may be tightly scheduled and confined to certain times and even days of the year, for others they may be integrated directly into hydroelectric operations such as peaking or load-following, or they may be scheduled on an almost ad hoc/opportunistic basis. An example of a project where recreation flows are fully integrated into project operations is the Nantahala Gorge on the Nantahala River in North Carolina, where a robust economy actually relies on the daily peaking operations of an upstream hydroelectric project to provide whitewater recreation opportunities, on an almost year round basis. For that system, recreation flows are provided during the day in conjunction with the release of flows for power peaking, while flows are reduced during the evening when power demands are lower. The Clackamas River Project in Oregon represents a system where recreation flows for one of its regulated tributaries (Oak Grove Fork) are being considered on an ad hoc basis (as high flow conditions may allow), to provide for kayaking, even though such conditions may not occur on an annual basis. Other projects specify recreation flows on an annual basis during certain times of the year. For these types of projects, the recreation flow perhaps best resembles a series of short duration pulse flows similar to a flushing flow, but that are scheduled over a two – three month period (Figure 5).

1.4.2.6. Outmigration Flows

The release of a block of water during the spring months to support the outmigration of anadromous salmonid smolts and fry represents another form of PTF that is practiced in the Pacific Northwest and California Coastal areas. Perhaps the best example of this occurs in the Columbia River Basin of the Pacific Northwest where for many years there has been a systematic and coordinated release of flows (April – June) from dams throughout the basin as a means to facilitate the outmigration of smolts through the series of mainstem dams (CPMPNAS 1996). The release pattern for these flows exhibits a sharp increase (generally via spill) up to a certain level of flow, sustaining that flow for several weeks to months (depending on flow availability) and then decreasing the flows down to the baseflow (non-spill) condition.

1.4.2.7. Adult Attraction Flows

Under some conditions, hydroelectric and other water projects may provide a short duration flow release to stimulate and promote the upstream migration of adult anadromous fish. These generally target fall spawning fish whose migration patterns can occur coincident with natural low flow conditions and elevated water temperatures. Since adult movements are often stimulated by a rapid increase in flow (spate), a series of short duration (1-7 days depending on water availability) pulse releases of flow can be useful in stimulating upstream movements as well as providing some thermal benefits. In some cases, pulse flows of a sustained nature have been recommended. For example, to promote adult migration in the lower Klamath River, Zedonis et al. (2003) proposed three options of PTF, including one sustained pulse flow lasting four weeks (designed to provide thermal benefits), a series of short duration (1-2 day) pulse flows, and a hybrid of the two consisting of a series of short-duration pulses during the first part of the month followed by a reduced but sustained pulse release for the remaining period (Figure 6). The range in flow fluctuation associated with these PTF was from around 450 cfs (baseflow) to 1500 – 2000 cfs, a 3.5 to 4 fold increase. In regulated streams, the release of these types of PTFs generally coincides with programmed flow conditions that are typically the lowest of the year. Hence, the extent of dewatered channel margins is at its greatest and correspondingly with the release of PTF during this period substantial rewatering of the channel occurs.

1.4.2.8. Thermal Flows

For some hydroelectric projects, PTF are released at certain times of the year or under certain extreme conditions to specifically provide thermal benefits for fish. For example, coldwater releases from Shasta Dam to the Sacramento River are meant to match the thermal requirements of winter run Chinook salmon for spawning and egg incubation. In this case, the releases are on more of a sustained period (throughout the spawning and egg incubation period) rather than a series of pulses. However, one of the license requirements for the Madison River project in Montana requires that when water temperatures reach a certain level, a series of pulse flows are to be released during the cooler late evening hours to provide thermal benefits during the day. In general, depending on the flow release configuration of the dam (e.g., surface-spill; selective gates; hypolimnetic), the thermal characteristics of PTF can vary widely and must be considered relative to effects on BMI and fish communities.

1.4.2.9. Baseload Adjustments

In general, the flow release patterns from flood and water supply dams can be relatively constant over long periods of time (several months), with changes made only to accommodate system (reservoir filling) needs or to meet specific habitat objectives (e.g., increased flows during salmon spawning periods). The same is true of many hydroelectric projects that are operated as baseload facilities for which power generation is set at some constant level (based on powerhouse capacity) that essentially mirrors natural flow conditions (e.g., run-of-river project) and/or that is consistent with reservoir management objectives (e.g., flood-storage, lake level management for recreation, etc.). However, even these baseload projects that can maintain stable flows for long periods of time require periodic flow adjustments.

This is illustrated in Figure 7, which depicts the annual hydrograph of the Kerr Dam hydroelectric project on the Flathead River, Montana that is operated as a baseload facility. Such adjustments are typically associated with seasonal or monthly adjustments that target aquatic species life history needs such as spawning or rearing, that target reservoir management, or that attempt to mimic some percentage of the natural hydrograph. With respect to the latter, the general pattern of flow change is from a baseflow condition during the late summer through winter, increased flows during the spring, and then tapering back down to baseflow conditions. In some systems, the regulation of flows creates a temporal shift in the flow regime whereby flows during certain times of the year become higher than normal, for example during the drafting of a reservoir to create flood storage, and then become lower than normal during other times of the year such as whenever the reservoir is filling (Figure 8). Flow adjustments based on aquatic biota life stage needs may take on a slightly different pattern, with increases occurring during both spring and fall months to accommodate spring and fall spawning fish, while flows at other times (winter and summer) may focus on egg incubation and juvenile rearing.

Although technically not a PTF, to the extent the baseload adjustments result in a rewatering or dewatering of channel margins, they can potentially affect BMI and fish communities. With PTFs, it is the reduction in flow that is of most concern to BMI and fish as it can result in loss of productive habitats as well as stranding and trapping of organisms. In the case of baseload adjustments, such reductions are generally relatively small compared with the range of flow fluctuations associated with power peaking and load following. For example, flows recommended to provide for salmonid egg incubation are typically in the range of 2/3 of the flows provided for spawning (Thompson 1972). These types of adjustments would generally not result in large expanses of channel margins becoming dewatered, and therefore the loss to BMI production would likely be minor. However, if the reductions are rapid, some stranding of both invertebrates and fry and juvenile fish could occur. Ramping rate restrictions on the rate of flow reduction serve to reduce the potential for these types of impacts.

2. SUSITNA RIVER 1980S STUDIES – RIPARIAN LITERATURE

2.1. Introduction

Both existing patterns and predicted changes in the dynamics of vegetation under the flow regime presented by the Susitna hydroelectric proposals of the early 1980s were described in a number in reports of that era (Helm and Collins 1997; Riparian Vegetation Succession Report 1985 [UAFAFES 1985]; Impacts Assessment Downstream Vegetation 1986 [Harza-Ebasco 1986]). The authors of those reports assessed the relative importance of flooding, ice, wind and wildlife interactions in establishing and maintaining the vegetation patterns present across the Susitna River floodplain. Using the available data, the authors of these studies developed a successional model for the Susitna River floodplain that predicted and described a sequence of transitions from silt to herbaceous vegetation to willow (*Salix* spp.) to alder (*Alnus* spp.) to immature balsam poplar (*Populus balsamifera*) to mature balsam poplar to mature white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*). Together with observations of various disturbances to these successional pathways, the 1980s authors created a general conceptual model to describe the dynamics of the Susitna River floodplain and to predict impacts of the multi-stage, two-dam project under consideration at that time. The results and predictions of these studies are summarized below.

The 500 km of the Susitna River were divided into three distinct reaches based on different channel structures which reflected the amount of fluvial disturbance and subsequent vegetation and substrate structure: (1) the Upper River above the confluence of the Susitna and the Oshetna which was considered largely outside the influence of the proposed project, (2) the Middle River reach between the confluences of the Susitna with the Oshetna and the Chulitna rivers, an area that was characterized as having armored channels and a greater susceptibility to ice jams, and (3) the Lower River area immediately below the Chulitna confluence which contained a greater area of cobble than the other two reaches and graded into the lowest portion of the river where reduced gradients and greater widths resulted in slowed velocities and increased sand deposition. The 1980s studies of vegetation composition and structure, vegetation succession, and wildlife vegetation interactions were focused on the Susitna River from Chase (immediately upriver of Three Rivers Confluence) downstream to the Deshka River.

Authors of 1980s assessments of the vegetation dynamics in the Susitna River floodplain relied on a combination of aerial photographs (monochrome 1951 and 1980 1:48,000) and a series of site visits (marked plots 3 and 14 years on) to characterize the existing structure of vegetation within the influence of the proposed multi-stage Susitna hydroelectric project. Site visits occurred in both 1981 and 1984 and consisted of a series of randomly oriented, non-overlapping 30-m transects in which vegetation cover and stem densities by height class were recorded and the age of dominant woody vegetation was determined. This transect information was combined with helicopter surveys of the active floodplain in June 1981 from which successional stages were plotted on the 1980 series black and white aerial photographs (1:48,000) from hilltop to hilltop across the floodplain.

2.2. Types of Vegetative Communities

Helm et al. (1985) identified the Susitna River as qualitatively different from many other northern river systems based on their characterization of substrate-based identifiable communities within the youngest successional stage and the well-developed Birch-Spruce forest (*Betula papyrifera* and *Picea glauca*) characteristics of later successional stages within the river floodplain. The authors of the 1980s studies also identified the importance of herbivore browse in determining both vegetation structure and the rates and pathways of succession.

2.2.1. Early Shrub Stage

In the early 1980s studies, early successional communities common along the Susitna River floodplain and in portions above Talkeetna were dominated by a combination of herbaceous and willow vegetation (early shrub stage – see Figures 9 and 10). These types accounted for 5-10% of the vegetated land observed during aerial transects (1981). Early shrub stage communities as described had the lowest cover of the successional stages identified, with > 50% bare ground and most plants < 0.40 m tall.

The dominant plant species included yellow dryas (*Dryas drummondii*), balsam poplar, feltleaf willow (*Salix alaxensis*), variegated horsetail (*Equisetum variegatum*). Willow was found to dominate sites with better growing conditions while dryas was most common on sites with cobbles and coarse gravel substrates. Vegetation cover was consistently lowest on harsh, cobbly, yellow dryas sites where overstory development was stunted and balsam poplar could remain sapling-sized over 20-40 years of development. Balsam poplar communities themselves occupied dry, nutrient-poor sites with sand content > 90% in many cases. Sites with intermediate-textured soils were typically dominated by willows while those with the greatest vegetation cover and the finest-textured soils (silt > 60%) had a high cover of horsetail and also included sedges (*Carex* spp.) and cottongrasses (*Eriophorum* spp.).

Helm and Collins (1997) distinguished the vegetation communities of the Susitna from other northern rivers by identifying characteristic sub-communities associated with substrate differences that likely resulted from different intensities of flooding and soil deposition (Figures 9 and 10). Sites with fine textured soil and generally mesic conditions were dominated by horsetail while very dry sites with sand soil and overall poor conditions were characterized by juvenile Balsam-Poplar community.

Thinleaf alder (*Alnus incana* ssp. *tenuifolia*) appeared to grow more rapidly than other shrubs with 5-year-old-specimens averaging 1.5 m tall while same-aged balsam poplars averaged just

0.5 m. Willow stands typically had the most developed shrub community within the Early Shrub Stage studies and these shrubs typically formed the overstory. Balsam poplar and feltleaf willow were generally restricted in height by a combination of flooding and browsing. Early successional sites had high densities of browse species. Many stems in the areas sampled by the authors of early 1980s reports were judged too short to be browsed - stems had to be 0.40 m to be counted. Most feltleaf willow were taller than poplar, and just 4% of balsam poplar twigs were browsed while 76% of feltleaf willow twigs were browsed. Horsetail-willow and horsetail-balsam poplar sites were reported to provide the most substantial forage for moose. Close proximity to mid- and late-successional stands that provide cover allowed most of these sites to receive use by all age classes of moose across seasons. Authors of these early studies judged horsetail and dryas communities of little value to moose across seasons either due to insufficient browse or inaccessible browse categories (stems below a ~40 cm winter snow depths).

The plant communities of the Early Shrub Stage were judged to persist up to 10 years from the last major disturbance, however the authors note several major difficulties with accurately aging vegetation development on these sites. Floods frequently deposited sediments around, but did not destroy vegetation in many instances – the vegetation would be buried and then resurface. Aging of vegetation on these sites was thus difficult – balsam poplar measured as 50 to 60 cm in height might have put on 5 to 10 years of growth since the last major flood/sedimentation and an equal amount of growth under sediment.

2.2.2. Intermediate Stage

Progression of Early Shrub Stage vegetation toward mid-successional types of communities relied on the deposition of sands and silts and/or the deepening of adjacent channels and an associated rise in these sites above the elevation of frequent flooding. Minimization of disturbance from ice scour and fast water was also necessary for these communities to develop. Mid-successional vegetation generated in this away accounted for roughly one-fifth of the vegetated land within the floodplain as surveyed during the 1980s assessments. Intermediate stage vegetation was characterized by thinleaf alder (15 to 30 years after island stabilization) or immature balsam poplar stands (35 to 55 years after stabilization) although this later type was much less frequent than the alder type. A notable difference between the Early Shrub Stage and the mid-successional stages was the dramatic reduction in bare ground – litter and bluejoint (*Calamagrostis canadensis*) covers were 99% and 38% respectively.

Alder density was found to greatly increase over Early Shrub Stage stands (691 up to 6682 stems/ha) whereas balsam poplar declined (40,000 to 2623 stems/ha). This reduction in balsam poplar was attributed in part to the combined effects of crowding, competition and preferential browsing by moose. Additionally the nitrogen-fixing capabilities of alder may have advantaged it on the young, infertile soils of these sites – poplar does not grow well in the shade of alder during this development stage. In most of the alder sites examined, balsam poplar and alder heights were essentially equal, although the authors note that their observations of different aged alder stands suggest that once balsam poplar achieve the height of alder canopies they quickly double in height, overshadowing the alder and developing into the immature balsam poplar phase of the Intermediate Stage.

In immature balsam poplar stands, as in alder stands, there was very little bare ground – litter and bluejoint provided most of the ground cover. With larger balsam poplar and thinleaf alder stems, the overall stem density in these stands decreases; Sitka alder (*Alnus viridis* ssp. *sinuata*) however, tripled in density. Individual alder stems averaged the same age in both alder and immature balsam poplar suggesting that 20 years is the life expectancy of alder stems in this system while the age of balsam poplar (~44 years) and height (18 m) were more than double what was typically found in alder stands.

The effects of ice were evident in these stands – stems knocked down by ice are too rigid to spring back as the more resilient young stems of the early successional stage do but not so rigid that they as stems in the later successional stage. The bent stems typically re-sprout such that the site is still basically at the same stage that it was prior to ice scour event but it has a younger age structure as multiple new sprouts dominate the mean age distribution. This pattern occurs in localized positions along the river where jams occur frequently although the amount of damage and vegetation stages affected are dependent on the size of the ice jam – for example, investigators found that ice jams occurred every year at a cross-section near Whiskers Creek.

Although the total number of stems/ha available for browse was generally less in these mid-successional plant communities than in the earlier successional stage, the presence of shade tolerant species such as highbush cranberry, raspberry and prickly rose added to the diversity of browse available. The mix of forbs present on these sites was also noted as important to the diets of young calves and lactating cows. The density of both alder and balsam poplar stands contributed to their use as sites providing dense hiding and thermal cover.

2.2.3. Late Stage

The late successional stage as defined by the assessments of the 1980s consisted of mature and "decadent" balsam poplar as well as transitional balsam-poplar and paper-birch. The authors note that while paper birch-white spruce was the oldest forest type sampled during their investigations, this community was typically considered successional to other forest types. On the Susitna, these authors identified this community as capable of self-reproducing and suggest it be considered a flood disclimax state dominating from year 200 or more following disturbance.

2.3. Successional Dynamics

Mechanisms likely driving successional change and transition between vegetation community types identified during the Susitna APA studies of the early 1980s are summarized in Figures 9 and 10 (Helm and Collins 1997). Major successional pathways together with their relative importance (width of arrows) and a general "time after stabilization" are also depicted. Each compartment represents a representative vegetative community or habitat class by surface area:

Water → Barren → Early Shrub → Alder → Young Poplar → Old Poplar → Poplar Spruce → Birch Spruce

Several feedbacks and loops are incorporated into this conceptual model, intended to describe potential outcomes of disturbance agents across a range of return intervals.

The conceptual model used to analyze and predict downstream vegetation impacts from the project as proposed in the 1980s was based on this successional series.

2.3.1. Sources of Disturbance

The investigations of the 1980s concluded that disturbances caused by flooding – particularly the paired processes of erosion and sedimentation- together with wildlife interactions were the major factors regulating vegetation succession along the Susitna River. Establishment of vegetation was limited to certain time periods during the year and this may have been a response to rainfall and flood regimes. Disturbances caused by flooding and ice damming resulted in sedimentation of sites resulting in an accretion of sediments that in many cases made aging of plant communities difficult due to substantial buried growth. Retrogression to bare ground or water generally only occurred if flooding was sufficient to erode substrate from beneath plants.

Scour from ice jamming typically resulted in bent or scraped willows and juvenile and sapling balsam poplar in the Early Shrub stage and on Alder sites in the Intermediate Stage but did not appear to change vegetation types. Ice scour functionally increased browse as additional stems sprouted from the ice damaged diagonal or horizontal stem. Understory plant communities were typically sheltered from substantial ice damage by the larger woody trunks of the Alder communities – in younger sites ice frequently scraped surface sediments resulting in removal of both the substrate and the plant communities that had been growing there. A net increase in bare soil (Barren Sites – see Figure 10) resulted; ice was thus also a factor in the transportation of sediments to other sites.

On older sites, the primary means of colonization or regeneration was in gaps created by tree-falls. The canopy openings created tree wind throw, and associated tree tip-up mounds, provided elevated safe sites with mineral soils and increased sunlight which allowed paper birch and shrub mosaics to develop in the understory. Browse activity from both moose and arctic hare reduced vegetation heights on many shrubs in the earlier stages which allowed thinleaf alder to dominate rapidly. Beaver activity was common on a number of sites where they removed most balsam poplar stems.

2.4. Predicted Impacts

The plant communities occurring in the Susitna River floodplain below the Devil Canyon dam site proposed during the 1980s constitute the vegetation reported to be most likely affected by the 1980s proposed project. Under natural flow and ice regimes, physical disturbance – such as ice processes, open water flooding events and bank erosion and sediment deposition – interrupt or reset the successional processes and maintain a diversity of vegetation types in patches across the floodplain mosaic. An "active zone" was defined as the portion of the floodplain that elevationally and areally corresponded to Early Shrub and Intermediate successional vegetation communities and was described as the region where vegetation is regularly affected by river flows, flood and ice jam events (Figure 11). The location and extent of this active zone was identified as the area that would change with operation of the Susitna Hydroelectric Project as it was proposed at that time.

Differences in wetted surface area – corresponding to the area of additional channel substrate exposed by a drop in the river's discharge – were determined for discharges ranging between low flows of 5,100-23,000 cfs and high flows of 90,000-118,000 cfs for the Middle River. A number of key assumptions were subsequently made in the assessment of likely project impacts on vegetation including:

1. the lower limits of vegetation can ultimately be defined in terms of water surface elevation
2. water surface elevations can subsequently be correlated with main channel flows and flood events that are predictable
3. project impacts can be estimated by examining probable project effects on flows and flood events
4. channel degradation and aggradation will not occur during the license period in a significant manner
5. vegetation must remain above water for at least half the growing season (June through August) in order to both establish and become mature
6. natural variability (e.g., steep cutbanks, substrate characteristics) may establish local elevation limits for some of the sampled cross-sections, in addition to survey or data recording error
7. the active zone was defined in terms of discharge events, however the authors acknowledge that ice effects are also important within this zone.

Estimates of amount and stage of vegetation both within and beyond the active zone were dependent on several assumptions including:

1. the area of active zone under pre-project conditions is functionally in dynamic equilibrium and the estimated composition is one-third early successional to two-thirds intermediate successional stage communities
2. stationary coverage of vegetation by ice does not cause substantial seedling or sapling mortality
3. early successional stands were assumed to be ~12 years old, intermediate succession stands were assumed to be one-third alder at 35 years since colonization and two thirds immature balsam poplar at 70 years post colonization while barren areas were assumed to be colonized in a logarithmic fashion.

The lower limit of vegetation in the middle Susitna River under natural flow conditions was estimated to occur at an average discharge of 36,000 cfs at Gold Creek (average of mean summer flow of 25,000 cfs and mean annual flood of 48,000 cfs). The upper limit of early and intermediate successional communities – the functional lower limit of late successional communities – was determined to lie between the 5- and 10-year floods or 63,000 cfs and 74,000 cfs respectively. For modeling purposes, investigators used the conservative 10-year flood in their impact assessment.

The active zone in the middle Susitna River was thus approximated by the bank area between the elevation of the water surface of the 10-year flood and the average discharge of summer flow and mean annual flood. The acreage of active zone in the middle Susitna River under pre-project conditions was estimated at ~2,050 acres and ranging between 1,000-1,300 acres following various project stages. Over the multi-year period during which project operations were to be phased in (Stages I through III; Figure 12), increasing load demand was expected to further stabilize flows and reduce flood flows. Vegetation succession and channel encroachment was thus predicted to sequentially increase as project operations were staged. The overall acreage of early and intermediate vegetation communities were predicted to oscillate over the license period and beyond. The total area of these communities was expected to be about 20 percent greater by the end of the license period; over a 100-years with-project timescale, this increase was expected to convert to a net loss of 35 percent of area by these communities. Although the total vegetated area was expected to increase, early and intermediate successional communities were not predicted to dominate that new area.

Although predictions for the Lower River were constrained by data limitations and gaps, 1980s investigators suggested that vegetation community change in that area of the Susitna would parallel those predicted in the Middle River although at a lower magnitude (~20 percent less change than predicted for the Middle River). The large area of gravel bars noted just below the lower limit of the active zone under pre-project conditions were expected to contribute to a net increase in early and intermediate successional plant communities in the Lower River over and beyond the proposed license period.

In general, investigators felt that the active zone would narrow somewhat and occur at lower elevations as the project progressed.

A substantive assumption of the vegetation analysis conducted in the 1980s was that all underwater or barren areas would be colonizable within 5 to 10 years following exposure. The authors note, however, that scouring of fine sediments will occur early on with the dam operations flow regime, leaving mostly pebbles and cobbles following higher flow events transporting those finer soil particles downstream. Simultaneously, the reservoir system associated with the proposed projected was expected to trap essentially all fine particles, suspended load. This process of scour was expected to take between 5 and 10 years to progress downstream as far as the Gold Creek area. The authors stated that quantifying the effect of this sediment scour on vegetation colonization dynamics was not possible given the information available but note that higher elevations, then vegetated, would be unaffected while the lowest elevations expected to be exposed were already large gravel and cobble. The effects of scour were most likely to be evident in the middle elevations (referred to in project literature as “Band 3”) to at most a “moderate” degree. Similarly, the anticipated variability in ice cover in the Middle River between years was believed to provide sufficient respite from ice effects such that opportunity for colonization and establishment of plants on exposed substrates would not be significantly affected. Lower River reaches were expected to experience water levels below the lower limit of the active zone during ice staging with project and thus ice was predicted to have little or no effect on vegetation in the Lower River active zone.

2.5. Associated Wildlife Impacts

The project area supports a diversity of wildlife species typical of Southcentral Alaskan ecosystems including large game, furbearers, raptors, waterbirds and a variety of other small game and non-game birds and mammals. Moose were considered the most important big game species throughout the project area with densities ranging from about 0.8 to 1.5/km^2 from Devil Creek to Deadman Creek and from Butte Creek to the upper reaches of the Oshetna River. Moose densities reached their peak in the lower Susitna River with densities of about 1.5 to 4/km^2. Although moose were found to range through all habitat types within the proposed project area, riparian or lowland forest habitat near the river was preferred, particularly during overwintering and calving. The alteration of downstream habitats due to altered seasonal and annual river flow regimes was expected to reduce the size of river islands, result in a loss of fertilization effects of spring flooding and result in an overall decrease in early successional habitats. Seasonal changes in browse availability drive movements for large numbers of moose – the changes in vegetative community distribution described above were projected to result in net decreases to moose and other large herbivore populations unless early successional vegetation mitigation measures were enacted (largely burning to promote greater area of early successional communities).

3. DAM IMPACTS ON DOWNSTREAM CHANNEL AND FLOODPLAIN GEOMORPHOLOGY AND RIPARIAN PLANT COMMUNITIES AND ECOSYSTEMS

3.1. Dam Impacts on Downstream Channel and Floodplain Geomorphology

Dams affect the primary factors that determine the shape, size and overall morphology of a river, the supply of water and sediment, the sediment-water ratio and the caliber of the sediment load (Schumm 1977). In boreal rivers, dams also affect the timing, duration and locations of ice formation as well as ice thickness and ice freeze-up and breakup characteristics (Prowse and Conly 2002; Prowse et al. 2002; Prowse and Culp 2003; Church 2015). In spite of decades of investigation of the effects of dams on downstream rivers (Petts 1979, 1980; Williams and Wolman 1984; Ligon et al. 1995; Friedman et al. 1998; Graf 1999, 2006; Webb et al. 1999; Petts and Gurnell 2005; Magilligan and Nislow 2005; Fitzhugh and Vogel 2011; Marren et al. 2014), there are very few general models that predict how any particular river is likely to respond once a dam is emplaced (Grant et al. 2003). In fact, geomorphic theory and the results of numerous case studies of dam impacts have provided some basis for prediction, but more often the results of case studies have tended to highlight variation in response rather than consistency (Williams and Wolman 1984; Friedman et al. 1998; Ligon et al. 1995; Grant et al. 2003; Fassnacht et al. 2003; Vadnais et al. 2012). Much of the variation in response to the dams is probably due to the presence of exogenous factors such as bedrock, vegetation, coarse colluvial, paleoflood, debris flow or glacial or fluvioglacial deposits, or intrinsically low sediment transport rates, and as such, the geological setting and geological history of the dam and dam-affected reaches must be factored into the below-dam assessment (Swanson et al. 1985; Webb et al. 1999; Grant et al. 2003; Fassnacht et al. 2003; Curran and O'Connor 2003; O'Connor et al. 2003; Vadnais et al. 2012).

The reported range of downstream geomorphic responses to the change in the ability of the river to transport sediment and the amount of sediment available for transport below a dam include: channel degradation or aggradation, channel narrowing or widening, bed material coarsening or fining, planform change, change of gradient, tributary degradation or progradation, as well as changes to floodplain connectivity and morphology (Kellerhals and Gill 1973; Petts 1980; Williams 1978; Williams and Wolman 1984; Carling 1988; Lagasse 1980; Germanoski and Ritter 1988; Church 1995; Brandt 2000; Grams and Schmidt 2002; Svendsen et al. 2009; Marren et al. 2014). There are also reported instances where dams have had very little or no effect on channel morphology (Williams and Wolman 1984; Inbar 1990; Fassnacht et al. 2003; Vadnais et al. 2012). Regardless of whether the dams have caused significant geomorphic response in the downstream channel, in all cases there are ecological consequences (Ligon et al. 1995; Rood et al. 2003). Additionally, the time necessary for response to dam emplacement and operation ranges from months to millennia, and the direction of the response may change over time (Petts

1979, 1980; Williams and Wolman 1984; Friedman et al. 1998; Church 1995; Gaeuman et al. 2005; Church 2015).

Various methods have been proposed for assessing the downstream morphological and sedimentological impacts of dams. These include: (1) those based on Lane's (1955) conceptualization of the balance between grain size, water and sediment discharge and slope (Schumm 1977; Brandt 2000); (2) empirical methods for estimations bed degradation (Calay et al. 2008); (3) dimensionless variables based on the ratio of sediment supply below to that above the dam (S*) and the fractional change in frequency of sediment-transporting flows (T*) (Grant et al. 2003); and (4) changes in sediment supply and transport capacity, the Shields number for channel competence and the ratio of pre-dam to post-dam flood discharge to scale channel change (Schmidt and Wilcock 2008). To some degree these approaches have been successful, but the downstream effects of dams cannot be analyzed solely by looking at the dam effects on hydrology and sediment flux independent of its broader geological setting (Grant et al. 2003).

3.2. First-order Impacts: Changes to Primary Physical Drivers of the Fluvial System Including Hydrology, Water Quality, Sediment Supply and Ice Processes

3.2.1. Hydrology

One of the primary effects of dams is inversion of the natural hydrograph where high flows are stored in the spring and released at varying rates for various purposes over the remainder of the year (Graf 2006; Fitzhugh and Vogel 2011). Review of the 36 largest dams in the United States by Graf (2006) indicated that the greatest effect of the dams was a reduction in peak flows, which on average were reduced by 67 percent. Minimum flows were on average 52 percent higher than unregulated flows, flow direction reversals increased by 34 percent compared to unregulated flows and flow up-ramp rates were on average 60 percent higher than under unregulated conditions. On more than half the large rivers in the United States the magnitude of the mean annual flood has been reduced by more than 25 percent (Fitzhugh and Vogel 2011). The downstream extent and magnitude of the altered flow regime depends on tributary inflows and whether the tributaries are themselves also regulated (Williams and Wolman 1984; Magilligan and Nislow 2005; Graf 2006; Fitzhugh and Vogel 2011). On the boreal Peace River downstream of the Williston Dam mean winter flows were on average 250 percent higher and annual peaks (1-, 15-, 30-day highs) were on the order of 35-39 percent lower than those that would have occurred under a natural regime (Peters and Prowse 2001). However, immediately below the dam the winter flows have been increased by 500 percent (Uunila and Church 2015). Although the effects of regulation are most evident near the dam outlet, they are also clearly evident 1,100 km downstream (Peters and Prowse 2001). In addition, the regulation of the Peace River has also reduced the downstream flow variability. However, despite the reductions in peaks and variability, the downstream hydrograph is far from flat and retains the basic shape of the pre-regulation hydrograph due to the strong influence of tributary inflows below the dam (Church 1995). Similar changes to the annual flow regime with reduced spring and summer flows and increased winter flows have been reported for other boreal rivers where flows have been regulated by single or multiple dams: the River Fortun in Norway (Fergus 1997), the Saint Maurice River in Quebec (Vadnais et al. 2012), the Lena River (Ye et al. 2003) and Irtish River (Yang et al. 2004) in Siberia and the Volga-Akhtuba Rivers in Central Russia (Gorski et al.

2012). However, not all rivers below dams have inverted flow regimes. Flow management on the Ouareau River in Quebec has maintained the seasonality of flood flows downstream of the dam, even though the magnitude of the flood flows below the Rawdon Dam is reduced (Landry et al. 2013). In contrast, on the Matawin River downstream of the Matawin Dam, the flow regime has been inverted and floods flows below the dam do not occur in the same season as those above the dam (Landry et al. 2013).

3.2.2. Water Quality

Development of large-scale hydroelectric dams has not been prevalent in the past 40 years in the United States. Despite this fact, intensive investigation and evaluation of environmental and social impacts of existing hydroelectric facilities has been conducted demonstrating some consistent observations. Several components of the riverine ecosystem are altered and have downstream effects with the presence of a large-scale hydroelectric facility. These components (e.g., physical processes, water quality, biota, etc.) are intertwined with one having an effect on one or more of the others.

One of the more obvious processes affected by the presence of a dam, especially on a glacial runoff river, is alteration of sediment delivery to downstream areas. Despite having obvious consequences to sandbar development and influence on riparian vegetation patterns (Nilsson and Svedmark 2002), a reduction in sediment transport and water clarity (i.e., turbidity) occurs. Ward and Stanford (1983) define a linkage between transport of coarse particulate organic material (CPOM) and availability of fine particulate organic material (FPOM) at points downstream based on position of a dam in the drainage (headwater versus lower reach). CPOM and FPOM are transported with inorganic particles and represent the origin of dissolved organics in fresh water including nitrate, nitrite, and soluble reactive phosphorus. Ammonia is generated in reducing aquatic environments where dissolved oxygen concentrations are low.

Rosenberg et al. (1997) examine the influence of an altered hydrologic pattern in northern rivers where spring flows are attenuated and winter flows enhanced due to energy demands during this portion of the year. The significance of this shift in timing for peak in hydrograph is that delivery of particulate organics occurs from upstream areas of the drainage during the biologically inactive period of the year (e.g., winter season). Depending on position of hydroelectric development in the drainage delivery of particulate organics to downstream reaches can be extensive with significant impacts to productivity. The entrainment of particles (inorganic and organic) upstream of the dam can have long-lasting effects downstream by increasing water clarity and stabilizing substrate. The combination of increased water clarity and substrate stability would promote a hypothetical increase in photosynthesis-to-respiration ratio (Ward and Stanford 1983). Extent of this effect downstream is based on occurrence and size of tributaries as documented by Stevens et al. (1997) where notable changes were described in mainstem water quality conditions on the Colorado River in Grand Canyon, Arizona. The authors evaluate and validate components of the Ward and Stanford (1983) Serial Discontinuity Concept integrating changes to water quantity and timing, physical properties and downstream water chemistry characteristics.

3.2.2.1. Water Quality Downstream of Dams

Turbidity of downstream outflow from reservoirs can be reduced and changes depositional patterns in the riverine system. The downstream effects are dependent on reservoir conditions and how suspended particles move through the system. Inflow to the newly formed reservoirs may be influenced by turbidity currents, especially when source water is from glacial origins. Turbidity currents are important not only for their contribution to the flow patterns within a reservoir, but because they can carry silt for a long distance into it, depositing some of it on the way, and so contribute to the formation of bottom-set deposits. The path and sequestration of highly turbid water in the reservoir will differ during the year based on volume of outflow and extent of stratification that occurs. The turbidity current is a sediment-laden patch of water that has higher density than clear, receiving water and moves through the clear water because of the higher density. These reservoir effects are transferred downstream to the river.

Decomposition of submerged vegetation often leads to a depletion of oxygen in the depths of the reservoir. Some of the conditions that build in the reservoir can be transferred to the downstream riverine drainage. The extent of impact from the reservoir depends on the timing and volume of water passing through the dam and on downstream tributaries to the area immediately downstream of a dam. The profile of most reservoirs, as compared with natural lakes, may permit the accumulation of a mass of stagnant water in the deepest part against the dam (Tyler and Buckney 1974). This bottom layer can become anoxic (Fiala 1966), reduced substances such as sulfide, ferrous, and manganous ions may accumulate. Nutrient substances may be leached from the underlying soil or released by the decomposition of submerged vegetation. The flooding of previously dry ground may lead to the release of toxic substances there either naturally or as a result of human activity. The alteration of the erosion pattern and sedimentation may lead to the release of pollutants (such as mercury) which are known to accumulate in sediments and be transferred downstream.

The complex flow pattern in many reservoirs may have an important influence on the downstream temperature regime. In summer, solar radiation on the reservoir will be converted to thermal energy that will heat the epilimnion but have little effect on the hypolimnion. Thus, the epilimnion serves as a trap for heat that would otherwise have served to warm the water downstream of the dam. In winter, after stratification has broken down, some of this heat will enter the outflow. The overall effect, therefore, makes the stream below the dam cooler in summer and warmer in winter than it was before the dam was built.

Hydroelectric developments constructed on the main stem of rivers can cause water quality to deteriorate when organic wastes settle in reservoirs, decompose anaerobically, and transferred downstream. This can reduce the biological assimilative capacity of the rivers and is especially true for reservoirs with long retention times. The assimilative capacity of the Saint John River has been reduced in this way (Dominy 1973). Fish-kills can occur in areas of a reservoir due to shortages of oxygen (Ruggles and Watt 1975). Severe oxygen depletion has been observed in summer and winter in the Notigi Reservoir, Manitoba, after the Churchill River diversion (Bodaly and Rosenberg 1990).

In contrast to effects of low dissolved oxygen concentrations above the dam, gas supersaturation results in gas bubble disease and may be a cause of fish mortality downstream of dams. This has usually been considered to be the result of heavy spillway discharge to downstream areas of the dam (Brooker 1981). MacDonald and Hyatt (1973) showed that the concentrations of dissolved oxygen and nitrogen gases were substantially increased when water passed through turbines operating at low load levels. Concentrations of dissolved nitrogen gas were increased as much as 20 percent above atmospheric equilibrium.

Methylmercury problems in fish are confined to the reservoirs themselves and short (<100 km) distances downstream. Temporally, methylmercury contamination in reservoirs can last 20–30 years or more; for example, methylmercury levels in predatory fish in boreal reservoirs of Canada and Finland can be expected to return to background levels 20–30 years after impoundment (Bodaly et al. 1984; Bodaly and Hecky 1979; Hecky et al. 1991; Kelly et al. 1997). Louchouarn et al. (1993) suggested that long distance atmospheric transport of mercury and suspension of the humic horizon from flooded soils are important in mercury cycling. Fish and invertebrates downstream of reservoirs also can have elevated methylmercury concentrations in the absence of generating stations (Johnston et al. 1991; Bodaly et al. 1984), apparently because of the transport of methylmercury in water and invertebrates. This second kind of downstream transport of methylmercury probably extends for <100 km but may be a more common occurrence than elevated levels caused by fish feeding on injured fish.

3.2.3. Sediment Supply

For all intents and purposes large dams can be considered to have 100 percent trap efficiency for all sediment sizes (Williams and Wolman 1984; Meade et al. 1990; Graf 2006), whereas smaller dams that have less storage capacity can have a much wider range of trap efficiencies ranging from 10-90 percent, or higher (Brune 1953). The downstream impact of the dam on channel and floodplain processes is dependent to a great extent on the ratio of the sediment supply below the dam to that above the dam (Grant et al. 2003). If the upstream supply is low there will be less of an imbalance below the dam and therefore there are unlikely to be significant morphological effects (Fassnacht et al. 2003). If the transport capacity of the river below the dam is low due to intrinsically low competence, the reduction in sediment supply from above the dam may also result in a very muted channel response (Vadnais et al. 2012). Additionally, if the sediment supply to the river below the dam is high, the effects of the dam tend to be mitigated rapidly as well (Fergus 1997). However, the more general case is that the downstream impacts of the dam due to the truncated sediment supply from above the dam are most directly influenced by the rate at which sediment is resupplied to the channel from tributaries, hillslopes and channel erosion (Grant et al. 2003; Petts and Gurnell 2005; Arp et al. 2007). Sediment mitigation can occur within a few miles of the dam (Svendsen et al. 2009) or it may not occur fully for hundreds of miles below the dam (Williams and Wolman 1984). Depending on the geological characteristics of the watershed and the location of the dam within the watershed, the amount and types of sediment delivered to the channel downstream of the dam can be different from those derived from above the dam (Church 1995; Pitlick and Wilcock 2001).

3.2.4. Ice Processes

Flow regulation downstream of dams located on boreal rivers significantly affects the location, timing, duration and thickness of ice cover (R&M Consultants 1984, 1985; Prowse and Conly 2002; Prowse et al. 2002). Regulation causes the release of relatively warm water (typically 0.5 to 4.0 C) (Keenham et al. 1982) from the dam and this can affect both the mean date of freeze-up (typically as much as 5 weeks later on the Peace River) and the break-up which tends to occur about 1 week earlier (Andres 1996). On the Peace River, because of the warm water releases from the dam, there may be no ice formation on the first 60 to 108 miles of the river. Farther downstream, only intermittent ice cover develops and there has been a significant delay in the initiation of freeze up and the overall ice season in the post-regulation period. At the downstream end of the Peace River, regulation does not appear to have significantly affected the time or duration of the main ice season (Prowse et al. 2002; Uunila and Church 2015). Hydro-peaking on regulated rivers enables frazil ice to form throughout the winter because of the persistence of open water below the dam, which can result in a very prolonged period of ice cover development on regulated rivers (She et al. 2012). Regulation induced higher flows in the fall and early winter in the upper reaches of the Peace River can result in ice formation as a result of consolidation rather than juxtaposition that in turn leads to the production of a thicker ice cover and a rough undersurface that causes water levels to rise on the order of 2 to 3 m rather than about 1m under pre-regulation conditions. As a result, the stage rise at freeze-up can exceed that at break-up, and stage rises produced by a consolidated ice cover may persist through the winter, a duration much longer than that of any open-water flood (Uunila and Church 2015). A combination of warmer winters and warmer water has increased the frequency of mid-winter break-ups and ice runs in the post-regulation period on the Peace River (Uunila and Church 2015). On Canadian Rivers in general, break-up flood stages exceed the largest open-water flood stages by 1-2m (Smith 1979; Smith 1980; Prowse and Conly 2002).

The most severe ice jams tend to form where there are constrictions, sharp bends and islands in the rivers (Smith 1980; Uunila 1997; Smith and Pearce 2001) and they tend to form in the same locations over time (Harza-Ebasco 1985). Significant ice-jam induced flooding occurs upstream of the ice jams (Beltaos and Burrell 2002) and ice jam surges and runs tend to create short duration floods with very high sediment concentrations (Moore and Landrigan 1999; Prowse and Culp 2003; Ettema and Zabilansky 2004; Ettema 2008; Durand et al. 2009).

Flow management to control downstream ice impacts have included release of higher flows in the freeze-up period to encourage ice formation at higher elevations and reduced flows in the break-up period (Uunila and Church 2015).

3.3. Second-order Impacts: Altered Hydraulics, Sediment Transport, Ice Processes and Channel and Floodplain Morphology

Second –order impacts primarily relate to the impacts of the dam-induced changes to the hydrology and sediment supply on channel and floodplain morphology and connectivity as well as fluvially-driven hydraulics and sediment transport processes (Figure 1). In the case of the ice-affected boreal rivers, dam impacts also include the effects of ice processes on floodplain and channel morphology as well as hydraulics and sediment transport.

3.3.1. Hydraulics and Sediment Transport

Various methods have been proposed for assessing the downstream hydraulic and sediment impacts of dams. These include: (1) those based on Lane’s (1955) conceptualization of the balance between grain size, water and sediment discharge and slope (Schumm 1977; Brandt 2000); (2) empirical methods for estimation of bed degradation (Calay et al. 2008); and (3) changes in sediment supply and transport capacity, the Shields number for channel competence and the ratio of pre-dam to post-dam flood discharge to scale channel change (Schmidt and Wilcock 2008). To some degree these approaches have been successful, but the downstream effects of dams cannot be analyzed solely by looking at the dam effects on hydrology and sediment flux independent of its broader geological setting (Grant et al. 2003).

Grant et al. (2003) proposed the term "lability" to describe the potential for adjustment of a channel downstream of a dam. They concluded that lability is a function of: (1) the transportability of the bed sediment which is indexed by its grain size relative to the shear stresses exerted by the flow across the full spectrum of the discharge regime; (2) the erodibility of the bed and banks, as influenced by their cohesiveness and/or the prevalence of bedrock; and (3) the opportunity for lateral mobility within the limits of the overall width and topography of the valley floor. They concluded that taken together, these factors determine where and to what extent channel adjustments below dams can occur.

Grant et al. (2003) suggested that a downstream geomorphic response is most likely where the geomorphically effective flow regime has been altered and there has been a change in the frequency and magnitude of flows that are capable of mobilizing and transporting sediment. They proposed a dimensionless ratio (T*) between the pre-dam (Tpre) and the post-dam (Tpost) frequency of sediment transporting flows. In general, T*<1, since Tpre>Tpost because dams reduce peak flows and generally coarsening and armoring of bed sediments occurs below a dam which in turn increases the critical discharge necessary for bed mobilization. Since most dams have very high sediment trap efficiency, the downstream impacts due to the truncated sediment supply from upstream are most directly controlled by the rate at which sediment is resupplied to the channel below the dam from tributaries, hillslopes and channel (bed and bank) erosion. Grant et al. (2003) expressed the sediment supply relation as a dimensionless supply ratio (S*) of the below-dam sediment supply SB to the above-dam sediment supply SA, at a particular location below the dam.

Predicted downstream effects of dams can be expressed as a bivariate plot of T* and S* with a continuum of expected outcomes (Figure 13, Grant et al. 2003). Where T* is high and S* is low, the expected channel responses will be bed scour, channel armoring, bar and island erosion, channel degradation and channel widening. Conversely, where T* is low and S* is high, the expected channel responses will be fining of the bed, island and bar construction, channel aggradation and channel narrowing. However, Grant et al. (2003) concluded that there was a large indeterminate region in the T*-S* space and that this was the main reason for the wide variance in downstream responses to dams. They concluded that within this indeterminate domain it is difficult to detect and identify clear trends in channel response and that the geologically mediated channel history (glaciation, landslides, debris flows, bedrock outcrop) is most likely to assert a controlling role.

Ice jams on boreal rivers exert significant effects on both hydraulics and sediment transport. On Canadian Rivers in general, break-up flood stages exceed the largest open-water flood stages by 1-2m (Smith 1979; Smith 1980; Prowse and Conly 2002) and a given stage will be produced more frequently by ice jams than by open water floods (Beltaos and Burrell 2002). Uunila and Church (2015) report that in the post-dam period on the upper Peace River higher flows in the Fall have increased ice thickness with a rougher undersurface that causes water levels to rise 2-3m and that stage rises at freeze-up now exceed those at break-up and that freeze-up induced flooding can persist through the winter thus producing much longer duration floods than under open-water conditions.

The most severe ice jams tend to form where there are constrictions, sharp bends and islands in the rivers (Smith 1980; Uunila 1997; Smith and Pearce 2001) and they tend to form in the same locations over time (Harza-Ebasco 1985). Significant ice-jam induced flooding occurs upstream of the ice jams (Beltaos and Burrell 2002) and ice jam surges and runs tend to create short duration floods with very high sediment concentrations that may be 2-5 times higher than those of open-water floods (Moore and Landrigan 1999; Prowse and Culp 2003; Ettema and Zabilansky 2004; Ettema 2008; Durand et al. 2009). Ice jam induced floods and sedimentation are responsible for significant vertical accretion of floodplain and island surfaces (Moore and Landrigan 1999. Ettema (2002) and Ettema and Zabilansky (2004) concluded that ice does not significantly affect channel morphology but it does increase the irregularities in the channel planform and frequencies with which the channel cross section and thalweg alignment shift as well as bank erosion and meander migration, local scour and deposition. Ice transports a very wide range of sediment sizes mainly via anchor ice formation on the bed and subsequent rafting of the ice and attached sediment (Ettema 2008). The presence of an ice cover reduces the rate of sediment transport beneath the ice (Ettema and Daly 2004).

3.3.2. Channel Morphology

Below dams there are a range of channel attributes that can adjust in response to the changed hydrological regime and sediment supply. These include adjustments to the cross section, bed material, planform and gradient (Williams and Wolman 1984). The reported range of downstream geomorphic responses to the change in the ability of the river to transport sediment and the amount of sediment available for transport below a dam are extremely varied and depend to a large extent on the geological setting of the watershed that integrates water and sediment supply and valley floor width and slope as well as the occurrence of historical events such as glaciation, landslides and debris flows (Grant et al. 2003). Additionally, the location of the dam within the watershed affects the response of the downstream channel (Church 1995; Marren et al. 2014).

Reported channel responses to upstream dams include channel degradation or aggradation, channel narrowing or widening, bed material coarsening or fining, planform change from multi-channel to single channel, reduced or increased rates of meander migration, increases or decreases in sinuosity and increases or decreases in gradient, as well as tributary degradation in response to baselevel lowering or tributary progradation into the mainstem channel (Kellerhals and Gill 1973; Petts 1980; Williams 1978; Williams and Wolman 1984; Bradley and Smith 1984; Carling 1988; Lagasse 1980: Germanoski and Ritter 1988; Church 1995; Brandt 2000; Grams and Schmidt 2002; Svendsen et al. 2009). There are also reported cases where dams have had very little, or no effect, on channel morphology (Williams and Wolman 1984; Inbar 1990; Fassnacht et al. 2003; Vadnais et al. 2012). The time necessary for response to dam emplacement and operation ranges from months to millennia, and the direction of the response may change over time (Petts 1979, 1980; Williams and Wolman 1984; Friedman et al. 1998; Church 1995; Gaeuman et al. 2005; Church 2015). Regardless of whether the dams have caused significant geomorphic response in the downstream channel, in all cases there are ecological consequences (Ligon et al. 1995; Rood et al. 2003).

The effects of ice processes on channel morphology have been investigated by Smith (1979) who concluded that in ice-affected rivers the channel cross section area at bankfull stage was on the order of 3 times that of similar sized rivers where fluvial processes dominated and that the average recurrence interval of the bankfull flow was about 17 years in contrast to about 1.5 years. However, Kellerhals and Church (1980) concluded that the larger channels reported by Smith (1979) and Smith (1980) could be the result of channel entrenchment, channel icing or backwater effects from ice jams. Best et al. (2005) concluded that an increase in channel width existed on the Kuparuk River, Alaska as a result of increased bank erosion by floating ice where there was a transition from bedfast ice to floating ice. Boucher et al. (2009) concluded that ice jam effects were only morphologically significant if the recurrence interval was less than 5 years. Smith (1980) has suggested that there are four distinct geomorphic thresholds involving different river ice processes in northern boreal rivers. Each threshold marks a sudden landform response or change. The identified thresholds were: (1) threshold of channel width, (2) the threshold of irregular channel morphology related to the preferred location of ice jam, (3) the threshold of channel slope that determines the occurrence of anchor ice or surface ice cover formation and (4) the threshold of flow depth that determines the occurrence of channel icing that can lead to channel relocation and flooding at breakup. Uunila and Church (2015) concluded from their investigation of the Peace River that it was unclear if ice has any major effect on the overall channel form.

A shelf or bench below the floodplain that was occupied by heavily scarred shrubs was recognized by Boucher et al. (2009) on the Necopastic River in northern Quebec. They concluded that the two-stage channel was created and maintained by a combination of fluvial and ice processes: ice-jam flooding led to lateral erosion of the river bank, during ice-jam flood recession there was sediment deposition on the eroded surface, and deposited sediments were then reworked into a flat bench by fluvial events in the post-ice period. They concluded that the morphological impacts of frequent ice jams were more common where the river was entrenched and laterally confined. Uunila and Church (2015) also recognized the presence of a shelf that was located between the pre-regulation floodplain and the summer waterline which they concluded represented a developing, confined floodplain at an elevation that was determined mainly by ice scour and deposition.

The impacts of dams on ice processes and consequently on channel morphology are unclear and probably depend on the operation of the dam and its effects on the ice dynamics (Church 1995). Uunila and Church (2015) concluded that ice jam flooding provided the primary means of supplying sediment to the upper banks and floodplain in the post-dam period. However, because of the relatively localized impacts of individual ice jams, the spatial extent of ice-jam induced sedimentation was likely to be small. They also concluded that ice jams remained the dominant form of physical disturbance with freeze-up jams dominating in the upper Peace River and break-up jams dominating farther downstream in the middle and lower reaches of the river. Ice jam effects were much less severe in the lower river with a wide floodplain and sand dominated bed than they were in the middle and upper reaches of the river that were more confined and had gravel-cobble beds, a conclusion that was also drawn by Boucher et al. (2009) on the Necopastic River.

3.3.3. Floodplain Morphology

In general, floodplains are built by a combination of vertical and lateral accretion processes (Wolman and Leopold 1957) with the proportion of each process being dependent on the type of river being considered (Nanson and Croke 1992). This rather simplified view has to be tempered by: (1) the wide range of floodplain types that exist along rivers ranging from high energy, coarse grained braided planforms where vertical accretion processes dominate to lower energy and finer grained meandering planforms where lateral accretion processes dominate and to fine grained, laterally stable anastomosing planforms where vertical accretion of fine grained sediments and organics dominates (Nanson and Croke 1992); (2) with the realization that the type of floodplain varies spatially in most large river systems (Church 1995; Richards et al. 2002); (3) that biogeomorphic feedbacks (vegetation effects) effect both the construction and destruction of floodplains over time (Marren et al. 2014) and (4) that in boreal rivers where ice processes are significant, ice jam formation and breakup can have a major role in the sediment transport and deposition on the floodplain as well as on erosion and fragmentation of floodplain surfaces (Smith 1980; Church 1995; Smith and Pearce 2001).

The effects of dams on downstream floodplains have received relatively little scrutiny in the dam impacts literature (Marren et al. 2014). However, Marren et al. (2014) have suggested that the impacts can be grouped into either passive or active. Passive impacts primarily reflect hydrological and thus sedimentological (Meade 1982) disconnection of the floodplain from the existing channel as a result of reduced peak flows (on average 67%; Fitzhugh and Vogel 2011) below the dam leading to the formation of a terrace. Active impacts are the result of changes in geomorphological processes and include the impacts of dams on both hydrology and sediment supply: (1) vertical bed changes (aggradation or degradation) that can either further disconnect the floodplain (Kellerhals and Gill 1973) or mitigate the hydrological impact and reduce the impact of the reduced flow regime (Svendsen et al. 2009); (2) bed material fining (Fergus 1997) or coarsening (Lagasse 1980) with the latter potentially increasing the rates of lateral channel erosion (Williams and Wolman 1984); (3) channel narrowing or widening that can have opposite effects on hydrological disconnection of the floodplain (Petts 1980; Williams 1978; Williams and Wolman 1984) and (4) increased or decreased rates of bank erosion and lateral migration that either decrease or increase the rates of floodplain reworking over longer time spans depending on the hydrological regime and the erodibility of the floodplain sediments (Bradley and Smith 1984; Friedman et al. 1998; Shields et al. 2000). Provided that sufficient sediment is still transported downstream of the dam, new floodplain surfaces may form that are related to the new hydrological regime, but the elevation of the surface will be lower than that of the pre-dam floodplain (Lewin 1978). Where there is insufficient sediment to form a new floodplain, vegetation is likely to encroach into the channel and occupy lower bars and bar surfaces thereby extending the riparian zone into the channel (Uunila and Church 2015).

Preliminary results from geomorphological field studies and 2-dimensional hydrodynamic modeling on the Middle Susitna River (ISR Study 6.5 Section 5.1.3.5.5 [AEA 2014] and Tetra Tech 2014) indicate that the suite of geomorphic surfaces from gravel bars to primarily sand composition floodplain surfaces occupied by old vegetation (poplars, spruce and birch) result from a mix of fluvial and ice-driven processes. Active gravel bars and sparsely vegetated gravel bars are inundated at open-water flows with recurrence intervals of between 1 and 2.5 years indicating that they are fluvially dominated. However, floodplain surfaces from the youngest to the oldest based on vegetation composition and age are only inundated by open–water flows with recurrence intervals of between 7 and 50 years, which indicates that they are primarily ice-jam backwater or surge controlled.

The impacts of dams on ice processes and consequently on floodplain erosion and deposition are unclear and probably depend on the operation of the dam and its effects on the ice dynamics as well as the effects of the dam on the supply of finer sediments that form the bulk of the floodplain (Church 1995). Smith (1979); Smith (1980); and Best et al. (2005) based on hydraulic geometry relations have shown that channels affected by ice-processes tend to be wider and deeper than those formed by fluvial processes alone which would suggest that the effects of flow regulation would be commensurately larger. However, Kellerhals and Church (1980) concluded that the larger channels reported by Smith (1979) and Smith (1980) could be the result of channel entrenchment, channel icing or backwater effects from ice jams. Uunila and Church (2015) concluded from their investigation of the Peace River that it was unclear if ice has any major effect on the overall channel form. However, they did recognize the presence of a shelf that was located between the pre-regulation floodplain and the summer waterline which they concluded represented a developing, confined floodplain at an elevation that was determined mainly by ice scour and deposition. A similar shelf or bench below the floodplain that was occupied by heavily scarred shrubs was recognized by Boucher et al. (2009) on the Necopastic River in northern Quebec. They concluded that the two-stage channel was created and maintained by a combination of fluvial and ice processes: ice-jam flooding led to lateral erosion of the river bank, during ice-jam flood recession there was sediment deposition on the eroded surface, and deposited sediments were then reworked into a flat bench by fluvial events in the post-ice period. Uunila and Church (2015) concluded that ice jam flooding provided the primary means of supplying sediment to the upper banks and floodplain in the post-dam period. However, because of the relatively localized impacts of individual ice jams, the spatial extent of ice-jam induced sedimentation was likely to be small. Uunila and Church (2015) also concluded that ice jams remained the dominant form of physical disturbance with freeze-up jams dominating in the upper Peace River and break-up jams dominating farther downstream in the middle and lower reaches of the river. Ice jam effects were much less severe in the lower river with a wide floodplain and sand dominated bed than they were in the middle and upper reaches of the river that were more confined and had gravel-cobble beds, a conclusion that was also drawn by Boucher et al. (2009) on the Necopastic River.

3.4. Third-order Impacts: Riparian Ecological Response

In this section Third-order impacts, the ecological responses to First-order and Second-order impacts, are reviewed. First, Third-order impacts are presented in the context of channel and floodplain geomorphic processes and dynamics. Second, these impacts are reviewed from the perspective of dam effects literature documenting the ecological response of riparian vegetation and ecosystems to alterations of natural flow and flow-mediated fluvial disturbance regimes.

Dam impacts to channel and floodplain geomorphic processes have been characterized by Marren et al. (2014) as both passive and active in nature, as discussed previously in Section 3.3.2. In passive impacts the floodplain becomes an inactive alluvial surface relative to overbank flooding and associated sediment depositional processes. Floodplain ecological processes dependent upon flood and sediment regimes are altered changing the trajectory of riparian plant community succession and ecological functions associated with those communities. Active impacts, changes in the sediment:water ratio, result in changes in channel and floodplain forming geomorphic processes altering the type and character of floodplain surfaces available for vegetation establishment. Passive and active dam impacts are further examined below.

3.4.1. Passive Impacts (floodplain disconnection)

The primary passive dam impact to floodplain ecosystems, floodplain waterbodies and associated wetlands, has been called by Richards et al. (2002) a "terrestrialization" of the pre-dam hydrologically active river valley.

"River hydroregulation by dams results in a terrestrialization of the vegetation, associated with a reduced rate of turnover of the fluvial landscape, reduced rates of ecosystem change, reduction of channel and ecosystem dynamics and of mosaic detail, reduced flood frequency, and loss of habitat and age diversity" (Richards et al. 2002).

Dam operation's flow regimes that reduce peak flows reduce the extent of downstream active floodplain area compared to the pre-dam natural flow regime. As discussed in Section 3.3, reductions in peak flows effectively decouple channel and floodplain hydrologic and sedimentological processes. Church (2015), in summarizing Petts (1980) review of dam downstream geomorphic effects, describes the mechanics of the process and response of riparian vegetation:

"Mainstem flows reduced below the level of competence to move the river bed sediments, so the active channel simply shrinks within the pre-existing channel zone by progradation of vegetation (in this case there may be no further morphological response; the active channel has, in effect, ceased to be an alluvial channel."

"Progradation of vegetation" is the ecological response of riparian vegetation to altered flow and sediment regime resulting in vegetation establishment on lower elevation channel surfaces leading to channel narrowing or encroachment, a commonly reported downstream effect of hydroregulation (Johnson 1994; Johnson et al. 2012; Nilsson and Berggren 2000; Gilvear 2004). Reduction in peak flows also decouples floodplains and floodplain water bodies from the river channel resulting in a reduced active riparian floodplain area and over time a change in associated riparian and wetland plant communities and ecosystem functions (Kingsford and Thomas 1995; Lite and Stromberg 2005). The hydraulically abandoned floodplain vegetation mosaic changes from a fluvial disturbance driven shifting habitat mosaic to a static terrestrial dominated vegetation type characterized by autogenic successional rather than allogenic disturbance processes (Johnson et al. 2012; Scott and Auble 2002). The process of floodplain terrestrialization, resulting from the long term effects of dam reduction of peak flows has been documented by Johnson et al. (2012) in a forty year retrospective investigation of Missouri River cottonwood forest dynamics. In 1976 the authors tested two hypotheses concerning the long-term effects of dams on Missouri River floodplain (Johnson et al. 1976): (1) The lack of cottonwood regeneration downstream of dams on the Missouri River is caused by major reductions in peak flows and channel dynamics, after which the river ceases to create sandbars for seedling establishment, and (2) Evidence of declining reproduction of box elder and American elm, coupled with high reproduction densities of green ash, suggests declining diversity in late-successional forest stands. Both hypotheses were confirmed in 2012 forty years following initial forest stand sampling in 1969 and 1970. Unforeseen cumulative impacts, resulting from land clearing, floodplain conversion and altered flow regime, were reported to result in the invasion of non-native exotic plant species (Johnson et al. 2012).

An additional Third-order passive effect of dams in northern temperate and boreal rivers is the reduction in downstream floodplain ice disturbance processes immediately below dams in dam generated ice-free reaches (Rood et al. 2007). The downstream attenuation of ice disturbance processes changes, in those effected reaches, channel and floodplain disturbance dynamics that generate new cottonwood sites of establishment resulting in a change in cottonwood floodplain forest pattern (Rood et al. 2007; Scott et al. 1996).

3.4.2. Active Impacts (changes in geomorphological processes and functions)

As discussed in Section 3.3, active impacts result in changes in the processes of channel and floodplain formation due to alteration of both flood regime and sediment supply. Changes in channel migration patterns and floodplain turnover due to alteration of erosion and depositional processes directly affect riparian vegetation establishment dynamics and pattern. The characteristic shifting habitat mosaic of alluvial floodplains is the direct result of channel dynamics (Naiman et al. 1998). Floodplain vegetation mosaic composition and age structure is controlled by active channel and floodplain disturbance processes creating newly eroded or deposited channel margin and floodplain surfaces that are the establishment sites for riparian pioneer plant species in the *Salicaceae* family, cottonwoods and willows. Downstream changes in the patterns of floodplain surface formation and spatial distribution result in alluvial valley wide changes in floodplain plant communities dependent upon these geomorphic processes for establishment (Johnson 1994; Scott and Auble 2002).

3.4.3. Dam Effects to Natural Flow and Disturbance Regimes: Riparian Community and Ecosystem Responses

Riparian plant species life history characteristics, morphological traits and physiological tolerances include adaptations to natural flow and disturbance regimes (Bendix and Stella 2013; Lytle and Poff 2004; Rood et al. 2003; Scott et al. 1996). When flow and disturbance regimes are altered, downstream riparian plant communities will adjust to these new physical boundary conditions resulting in a new community composition, distribution and successional trajectory (Cooper et al. 2003; Johnson 1994).

In this section Third-order ecological responses to dam alterations to flow and disturbance regimes are reviewed. Riparian vegetation and ecosystem effects are summarized at a range of spatial and temporal scales relevant to riverine─riparian landscapes. Spatial scales include: local (grain, bedform, and barform), reach (channel and floodplain mosaic; patch dynamics; typically 10-20 times the active channel width), and river segment/corridor (geomorphic segment or riparian process domain) (Figure 14; Richards et al. 2002). Temporal scales, associated with spatial scale processes, include: Short term (1-10 years), Mid-term (10-50 years), and long term (50-200 years) (Figure 14; Richards et al. 2002).

3.4.3.1. Natural flow regime: surface and groundwater dynamics and gradients

Water sources for the establishment and maintenance of floodplain vegetation include precipitation, groundwater, and surface water (Cooper et al. 1999; Rood et al. 2003). Floodplain surface and groundwater hydrologic gradients, influenced strongly by the natural flow regime, are a controlling factor influencing local and reach scale riparian and wetland plant community composition, abundance and distribution (Bendix and Stella 2013; Naiman et al. 2005). Dam alterations to flow regimes−by changing the pattern of overbank flooding and decoupling of lateral floodplain water bodies resulting depression of shallow floodplain alluvial aquifers−have been reported to affect changes in riparian plant species richness (Nilsson et al. 1991; Jansson et al. 2000b), plant growth rates and productivity (Stromberg and Patton 1990), plant community composition (Merritt and Cooper 2000; Merritt and Wohl 2006), initiation of invasions of exotic plant species (Braatne et al. 2007; Cooper et al. 2003) and mortality of riparian forests (Rood and Mahoney 1990; Braatne et al. 2007). Dam alterations of floodplain pattern of water availability−the hydrologic surface water and groundwater boundary conditions under which a plant community has established−initiates a cascade of ecological responses where plant community composition shifts over time to accommodate the new hydrologic conditions. The temporal response of plant communities to alterations of water availability varies widely, from short to mid to long term effects, depending upon climate and degree of hydrologic alteration (Scott and Auble 2002; Nilsson and Berggren 2000). Dam effects studies have covered a wide geographic and climatic range with the majority of studies conducted in arid, semi-arid and temperate regions of North America and Europe (Braatne et al. 1996; Nilsson and Berggren 2000). A few notable studies have been conducted in northern temperate and boreal river systems (Church 2015; Lind et al. 2014; Nilsson and Berggren 2000; Jansson et al. 2000b).

An extensive literature concerning the physiological response of cottonwood species to drought stress imposed by river damming, flow diversions and subsequent water table depression has been reported since 1990 (Braatne et al. 1996, 2007; Rood et al. 2003). Results have shown that dam operations reduction in the frequency and magnitude of over bank flooding has led to lowering of shallow floodplain water tables resulting in water stress to riparian phreatophytes, shallow alluvial aquifer dependent plant species (Stromberg and Patton 1990; Auble et al. 1994; Rood and Mahoney 1990). Collapse of riparian cottonwood forests downstream of dams, resulting from floodplain water table depression, has been reported in western prairies of North America (Rood and Mahoney 1990).

3.4.3.1.1. North American Cottonwood Forests

Dam hydroregulation of a river's natural flow regime has been demonstrated to be a primary causative agent in the decline of riparian cottonwood forests, and associated plant communities, throughout North America (Rood and Mahoney 1990; Cooper et al. 2003; Scott and Auble 2002). Riparian cottonwood forests are dependent upon specific hydrologic and sediment regimes for forest reproduction and maintenance (Rood and Mahoney 1990; Braatne et al. 1996).

The ecophysiology of cottonwoods within riparian zones is well understood illustrating the dependence of riparian cottonwoods on stream flow (Braatne et al. 1996; Rood et al. 2003). Pioneer riparian tree and shrub species in the family *Salicaceae*, cottonwoods (*Populus* spp.) and willows (*Salix* spp.) have evolved an adaptation to release seed in synchrony with seasonal snowmelt-driven peak flows (Stella et al. 2006). Peak flows generate newly deposited or eroded mineral colonization substrates, and provide near-surface floodplain groundwater conditions, all necessary conditions for poplar and willow seedling establishment and recruitment (Braatne et al. 1996; Mahoney and Rood 1998). The timing of snowmelt spring flows, and of tree and shrub seedling release and dispersal, is critical to successful establishment and maintenance of riparian cottonwood floodplain forests (Braatne et al. 1996; Mahoney and Rood 1998). *Salicaceae* seed dispersal and seedling establishment have been reported to be affected by hydroproject operations that have eliminated spring snow-melt driven flow regime (Braatne et al. 1996; Cooper et al. 1999; Rood et al. 2003).

An empirical model, the "Recruitment Box Model" captures cottonwood and willow seed dispersal, flow response and recruitment requirements and has been successfully demonstrated on rivers throughout arid to temperate North America rivers (Mahoney and Rood 1998; Rood et al. 2003). The recruitment box model characterizes seasonal flow pattern, associated river stage (elevation), and flow ramping necessary for successful cottonwood and willow seedling establishment and has been used successfully in developing environmental flow regimes for restoring *Salicaceae* recruitment processes in dam hydroregulated rivers (Rood et al. 2005; Shafroth et al. 1998).

Seasonally fluctuating water tables in arid to temperate regions are a limiting factor in the establishment and maintenance of riparian phreatophytes, groundwater dependent trees and shrubs (Rood et al. 2003; Rood et al. 2007). As such, these species are susceptible to water stress, and subsequent mortality, when dam alterations impact natural flood pulses and reduce floodplain shallow aquifer recharge processes (Lite and Stromberg 2005). Reduced flows, and subsequent limited moisture availability, are reported to be lethal especially to establishing cottonwood seedlings and older cottonwood trees (Rood and Mahoney 1990). Although dam impacts to phreatophytic trees in arid and semi-arid climates have been widely reported (Rood et al. 2003), cottonwood in more humid temperate regions have been documented to be less dependent upon shallow alluvial aquifers as a water source (Rood et al. 2011). For example, recent studies have shown a progressive variation in cottonwood species rooting depth as a function of local climate and not as a differentiation across species (Rood et al. 2011). The authors conclude that cottonwoods are opportunistic with respect to water source reporting that rooting depth is a function of depth to available moisture and therefore cottonwoods may be characterized as "facultative" rather than "obligate" phreatophytes (Rood et al. 2011). For example, across arid to semi-arid cottonwood species (*Populus angustifolia* and *P. deltoides*), rooting depths have been demonstrated to be controlled by depth to groundwater (Rood et al. 2003, 2011).

3.4.3.2. Natural Disturbance regime: erosion, sedimentation and mechanical shearing

Natural flow and disturbance regimes generate and maintain the characteristic floodplain vegetation mosaic patch age structure, composition and distribution at reach and river segment scales (Naiman et al. 1998). Associated with natural flow regimes, erosional and sediment depositional processes are a primary control of open-water floodplain formation (Marren et al. 2014). Although the role of fluvial disturbance (erosion and sediment deposition) in the development of floodplain vegetation has been well investigated (Naiman et al. 1998; Rood et al. 2007), the role of river ice processes has seen limited study (Engstrom et al. 2011; Prowse and Culp 2003; Uunila and Church 2015; Lind et al. 2014).

The effect of river ice processes on riparian vegetation in northern temperate and boreal rivers has received little study world-wide (Engstrom et al. 2011; Lind et al. 2014; Uunila and Church 2015). Research to-date reports that river ice jam formation and break-up results in two primary types of vegetation disturbance: (1) mechanical shearing of vegetation from ice rafts transported along the channel edge and onto the floodplain surface, and (2) burial of existing plant communities by overbank deposition of entrained sediment (Uunila and Church 2015; Engstrom et al. 2011; Boucher et al. 2009). These types of ice disturbance have been reported to generate clonal reproduction in buried and mechanically sheared cottonwood (Rood et al. 2007).

In northern temperate and boreal rivers, ice processes, during river ice-breakup, have been reported to cause ice shearing and hydraulic erosion of channel and floodplain surfaces, and through the agent of ice jam backwater flooding resulting in local floodplain sediment deposition and surface aggradation (Uunila and Church 2015; Prowse and Culp 2003; Lind et al. 2014). Therefore, in northern temperate and boreal rivers, both open water and ice process driven erosion and sediment deposition generate new floodplain patches upon which pioneer riparian vegetation establishes. Overbank flood sediment deposition and burial of riparian vegetation is a significant floodplain vegetation disturbance process that also creates new mineral surfaces both along channel and floodplain margins as well as within the interior of existing floodplain plant communities (Rood et al. 2007; Lind et al. 2014).

Impacts of ice-related processes to riparian habitat typically occur during break-up when ice scours channel and floodplain surfaces and ice jam backwater floods deposit sediment on floodplain surfaces (Prowse and Culp 2003). During break-up, ice accumulation in meander bends can create ice dams elevating backwater surfaces, forcing meltwater to bypass the bend and scour a new meander cutoff, generating new side channels (Prowse and Culp 2003). Elevated backwater, resulting from ice dams, may also float ice blocks onto and through vegetated floodplain surfaces, causing mechanical shearing effects including tree ice-scarring and abrasion, removal of floodplain vegetation, and disturbance of floodplain soils (Engstrom et al. 2011; Rood et al. 2007; Prowse and Culp 2003). Uunila and Church (2015) in a study of ice effects on the boreal Peace River bank morphology and riparian vegetation report that riparian shrub communities on lower elevation surfaces to be repeatedly disturbed by ice jam scouring, shearing and sediment depositional processes. Similar ice disturbance processes have been anecdotally reported for the Susitna River, Alaska (Helm and Collins 1997). Although ice process effects have received limited world-wide study, the limited research reports ice disturbance processes to play an underappreciated role in the maintenance of young pioneer shrub vegetation on ice affected northern rivers (Rood et al. 2007). The 2012/2013 Riparian Vegetation and Riparian IFS Study team have observed extensive evidence of ice disturbance to Susitna River floodplain vegetation and soils in the form of tree ice-scars, mechanically disturbed soil stratigraphy, buried floodplain trees and shrubs, and deposited floodplain gravel and cobble deposits observed throughout Middle River surveys.

3.4.3.3. Invasive Exotic Plant Species

A Third-order impact to floodplain plant communities reported nearly universally in the dam effects literature is the invasion of exotic plant species into hydrodynamically altered riparian zones (Johnson et al. 2012; Braatne et al. 2007; Richards et al. 2002; Nilsson and Berggren 2000; De Waal 1994). The alteration of natural flow and disturbance regimes creates new physical habitat conditions─channel and floodplain physical surfaces with altered hydrologic gradients, sediment conditions and hydrogeomorphic regimes─that favor invasive exotic plant species life history adaptations over the historic native riparian vegetation (Braatne et al. 2007; Lytle and Poff 2004; Nilsson and Berggren 2000). Riverine─riparian corridors are particularly susceptible to exotic plant invasions as rivers act as dispersal corridors for exotic species propagules through seed dispersal mechanisms of hydrochory (flowing water) and wind (Richards et al. 2002). Exotic plant invasions capitalize on the desynchrony of native cottonwood and willows seed dispersal timing generated by altered natural flow regimes (Stella et al. 2006). Examples from the American southwest include extensive invasions of tamarisk (*Tamarix* spp.), Siberian elm

(*Ulmus pumilla*) and Russian olive (*Elaeagnus angustifolia*) found throughout dam altered stream corridors (Stromberg et al. 1996; Cooper et al. 2003). The ubiquity of documentation of invasive exotic plant species invasions of riparian zones following dam alterations of natural flow and disturbance regimes strongly indicates this is a predictable phenomenon (D'Antonio et al. 1999; Cooper et al. 2003).

3.5. Fourth-order Impacts: Feedbacks between Biological Responses and Physical Processes

Fourth-order impacts are feedbacks between biological responses and physical processes (Figure 1). These impacts follow as organisms, plants and animals adjust to hydroregulation changes to natural flow and disturbance regimes. As described in Section 2, riparian plant species and many riparian wildlife species are adapted to specific natural flow and disturbance regimes. Plant species and communities establish and develop along species specific environmental gradients of hydrology, sediment and soil characteristics, nutrient resources, temperature and light (Whittaker 1975). As these controlling physical variables change, plant species either survive or senesce altering plant community composition, distribution and succession. In riparian ecosystems, these biotic changes in response to changing environmental gradients occur throughout riparian communities and ecosystems and indirectly effect channel and floodplain geomorphic processes through alterations in channel roughness and sedimentation characteristics (Grant 2012; Marren et al. 2014; Petts and Gurnell 2005). This Fourth-order impact process has been described as a cascade of effects by a number of authors (Ward and Stanford 1983; Poff et al. 1997; Nilsson and Berggren 2000; Jorde et al. 2008; Burke et al. 2009) (Figure 1):

Fourth-order impacts → Second-order impacts → Third-order impacts → Fourth-order impacts

Fourth-order impacts → Third-order impacts → Fourth-order impacts

Channel narrowing, and decoupling of channel and floodplains, due to reduced peak discharges, vegetation encroachment, and subsequent channel incision, has been a widely reported response to hydroregulation reduction in peak flows (Ligon et al. 1995; Tal et al. 2004; Johnson et al. 2012; Marren et al. 2014). The new, deeper channel requires higher discharges to overtop adjacent floodplains (Ligon et al. 1995). This type of Fourth-order impact has been reported to result in a number of ecological effects such as decreased species diversity and standing biomass of fish (Ligon et al. 1995) and simplification of floodplain vegetation mosaic and associated riparian and aquatic habitat diversity (Amoros and Bornette 2002; Nilsson and Berggren 2000; Naiman et al. 2008). The example of hydroregulation reduction in peak flows, and attendant reduced flood regime, has been reported to result in a wide range of geomorphic and ecological responses, Third- and Fourth-order impacts, ultimately resulting in a diminishment of riparian ecological diversity (Nilsson and Berggren 2000, Naiman et al. 2005; Figures 15 and 16).

Although channel narrowing is a common response to reduced peak flows, Fourth-order impact responses are complex as reported by Friedman et al. (1998) for rivers in the Great Plains of North America. Friedman et al. (1998) reporting on dam effects on riparian forests in southern Great Plains rivers channel narrowing along braided reaches resulting from riparian tree establishment on newly exposed lateral channel margins. At the same time, in southern Great Plains rivers, the authors report a decline in riparian tree species reproduction associated with reduced channel migration and natural channel disturbance, therefore reducing new open mineral substrates required by these species for seedling establishment. These types of complex cascading Third- and Fourth-order impacts, and ecological responses to alterations of natural flow and disturbance regimes, have been reported extensively in the dam downstream riparian effects literature (Figures 15 and 16) (Petts 1984; Ligon et al. 1995; Nilsson and Berggren 2000; Bunn and Arthington 2002; Amoros and Bornette 2002; Petts and Gurnell 2005; Naiman et al. 2008; Osterkamp and Hupp 2010; Grant 2012).

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5. FIGURES

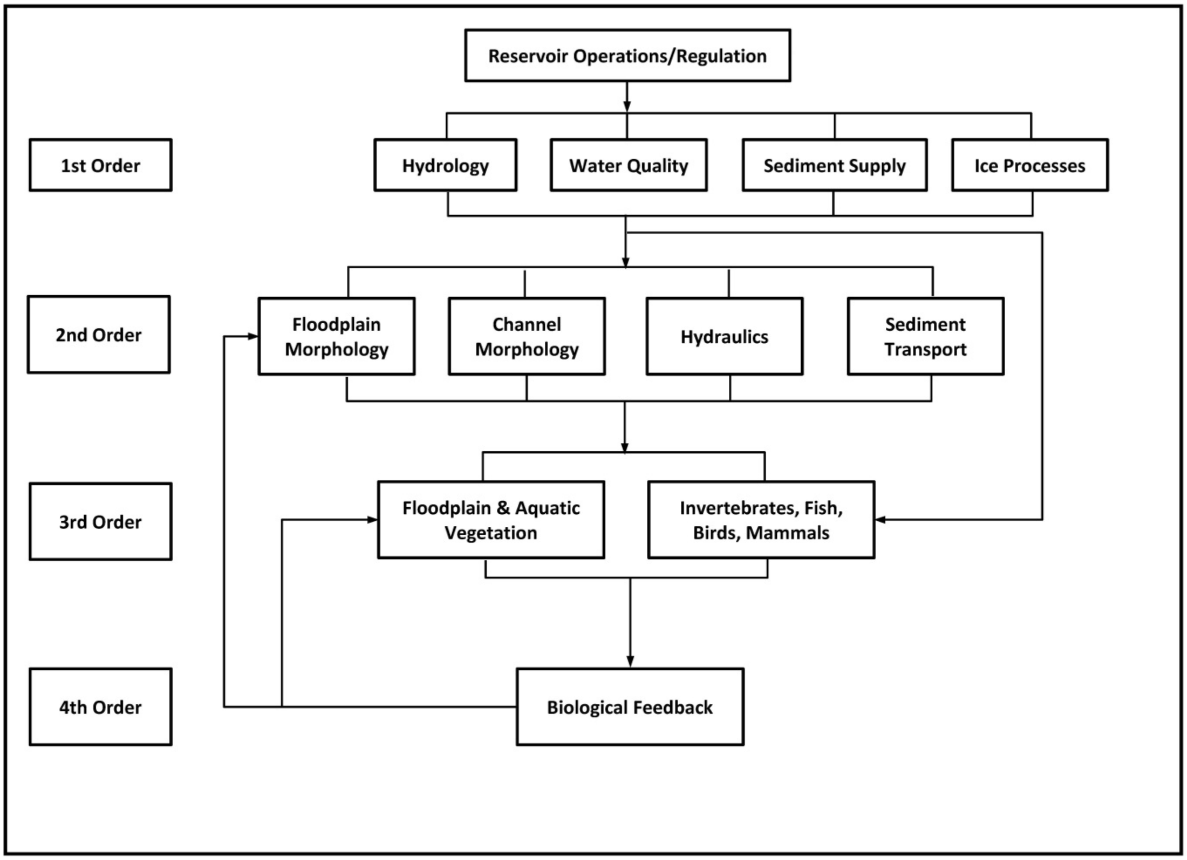


Figure 1. Hierarchy of physical and biological impacts caused by dam operations (Modified from Petts 1984; Jorde et al. 2008; Burke et al. 2009)

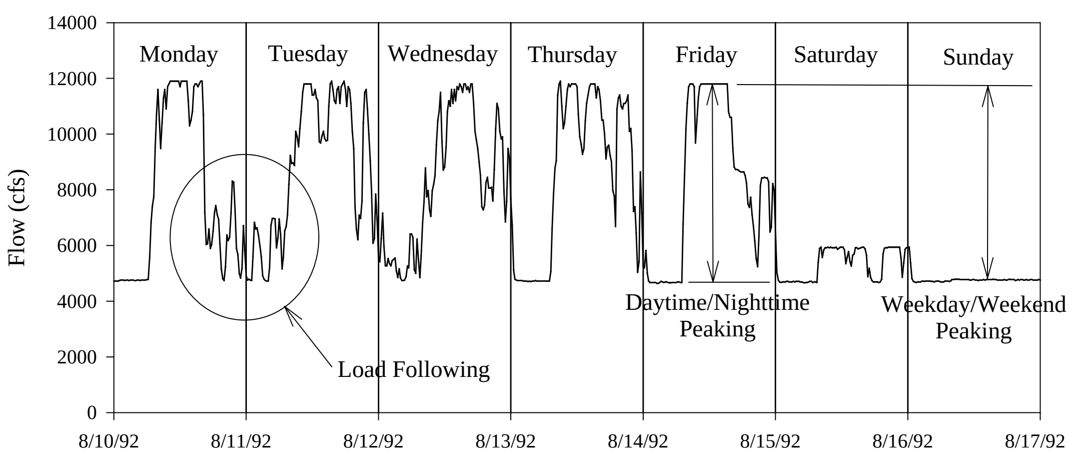


Figure 2. Example of hydroelectric power peaking and load following operations that result in frequent, large magnitude, short duration pulse type flows. Peaking and load following patterns are primarily evident during the weekdays. Data are from the Flathead River below Kerr Dam, Montana that was historically operated as a peaking/load following facility (adapted from Reiser et al. 2005).

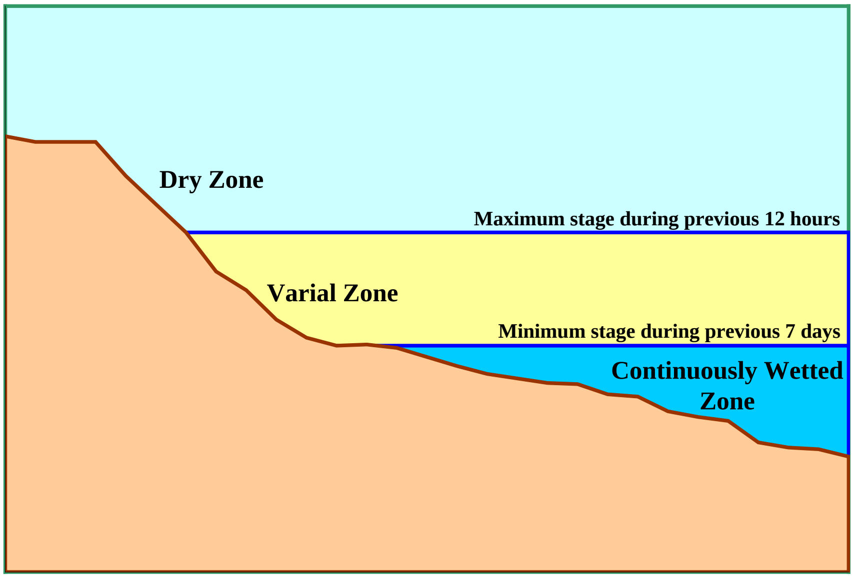


Figure 3. Example cross-section of a hypothetical channel margin that depicts extent of varial zone as defined by maximum stage of pulse type flow during previous 12 hours. Based on studies conducted on the lower Skagit River, Washington (adapted from Reiser et al. 2005).

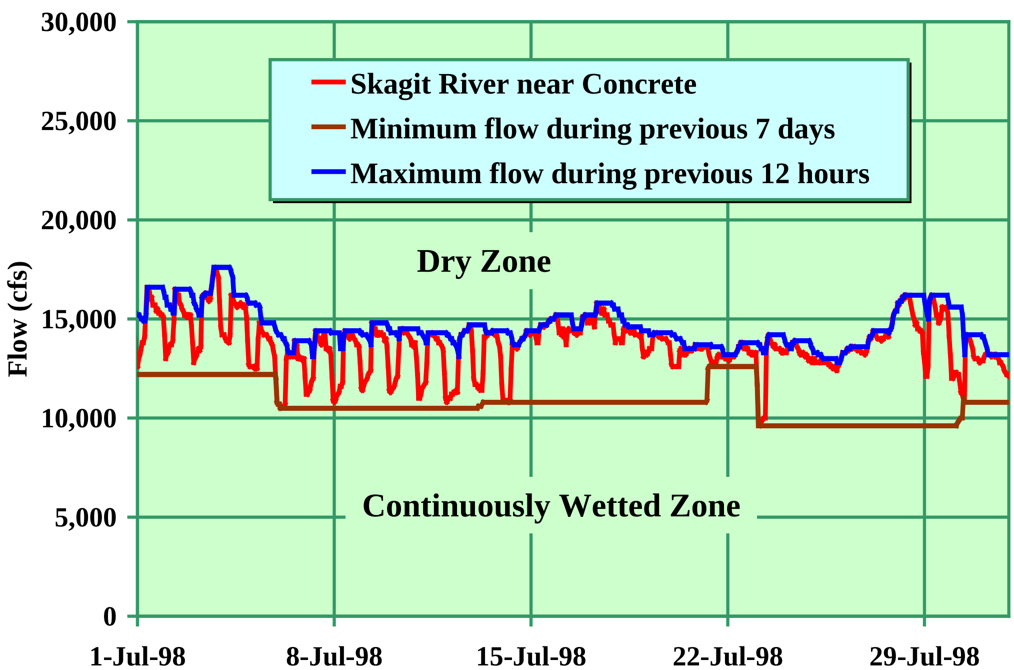


Figure 4. Example of pulse type flows in the Skagit River, Washington that have occurred in the past (1998) from load following operations of the Baker Hydroelectric Project (adapted from Reiser et al. 2005).

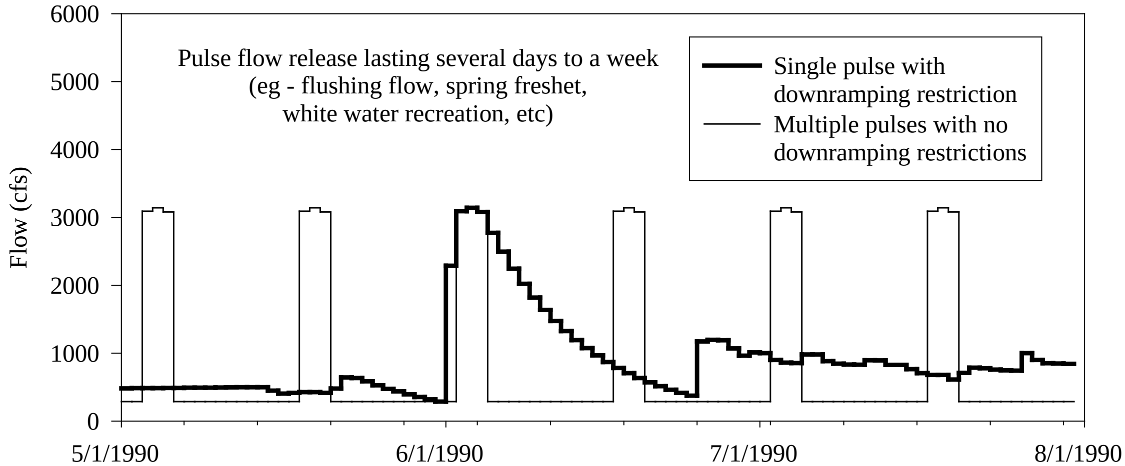
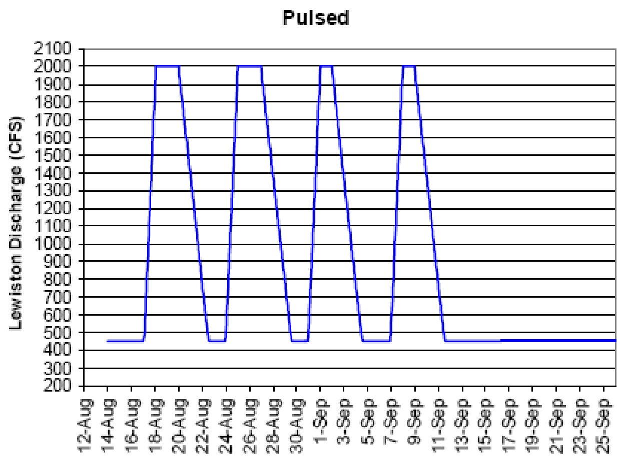
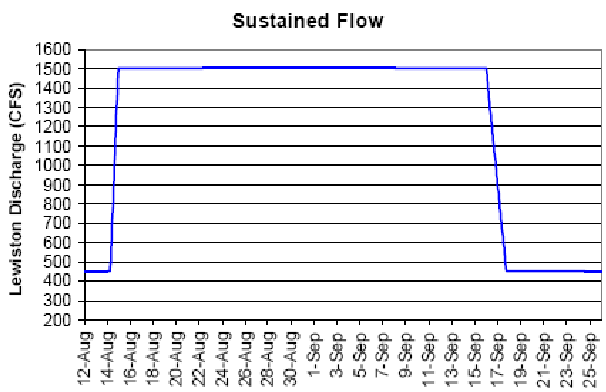


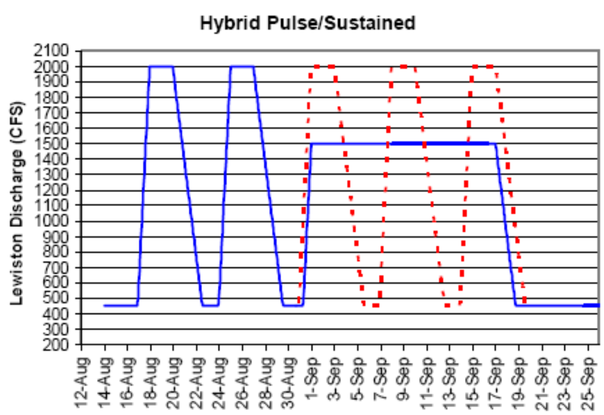
Figure 5. Examples of infrequent pulse type flows (PTF) that may be associated with flushing flows and recreation flows. Examples depict a PTF "with" and "without" downramping rate restrictions (adapted from Reiser et al. 2005).



A.



B.



C.

Figure 6. Various Pulse Type Flows considered for adult salmon attraction for the lower Klamath River, California. A. depicts series of PTF; B. depicts sustained PTF; C. depicts hybrid pulse and sustained PTF. Adapted from Zedonis et al. (2003) as presented in Reiser et al. (2005).

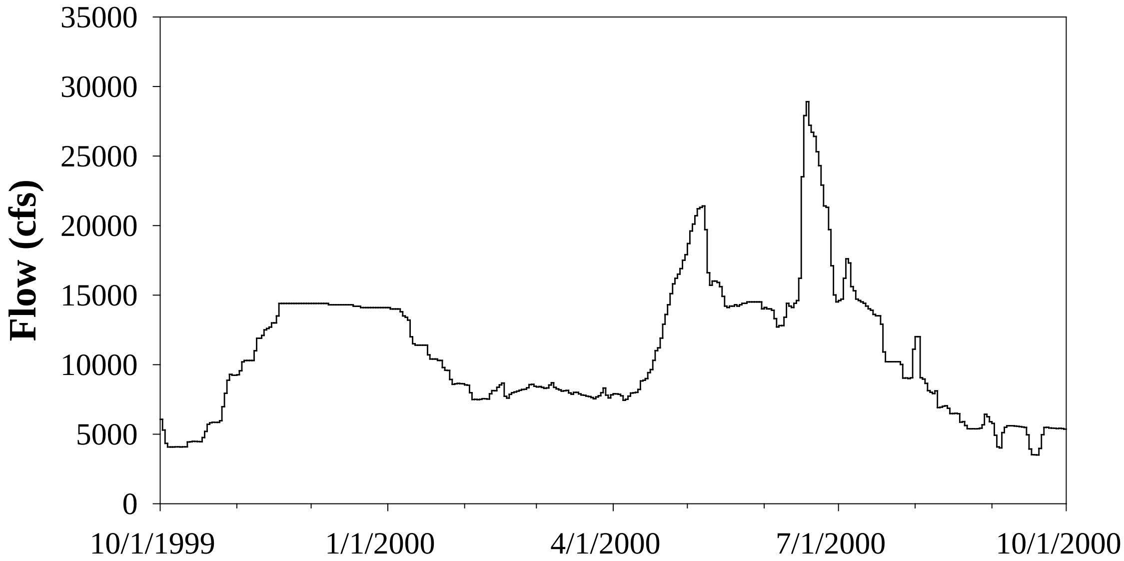


Figure 7. Example of a baseload operated hydrograph resulting from the operation of the Kerr Dam on the Flathead River, Montana for 1999 and 2000. The shape of the hydrograph is largely determined by resource management objectives that include Flathead Lake management, as well as natural flow conditions. Note that even under baseload operations pulse type flows can occur (adapted from Reiser et al. 2005).

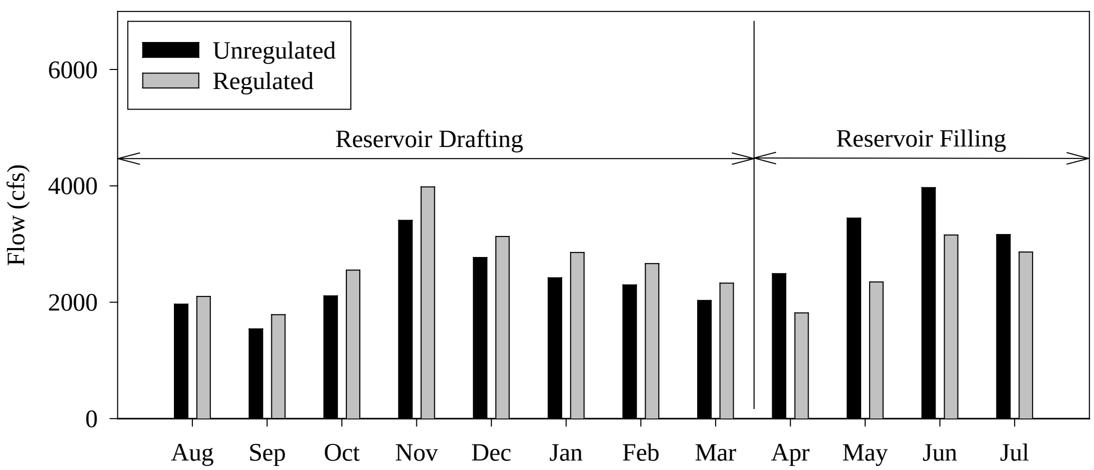
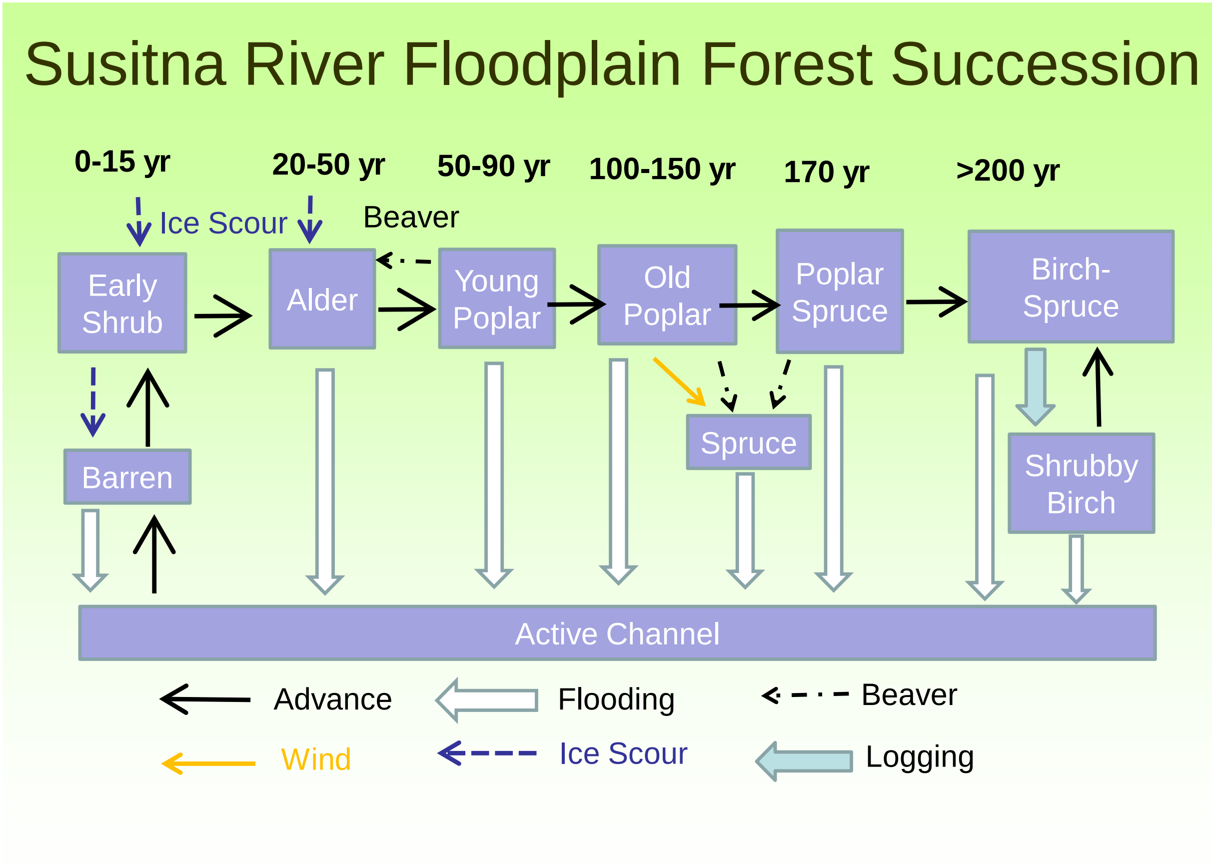


Figure 8. Comparison of regulated versus unregulated monthly hydrographs for the Flathead River, Montana, below Kerr Dam. Temporal shifts in the occurrence of peak flows results from reservoir drafting and filling (adapted from Reiser et al. 2005).



(after Helm and Collins 1997)

Figure 9. Helm and Collins (1997) Susitna River floodplain forest succession. Note: model depicts typical floodplain forests found in the Susitna River Middle River and Three Rivers Confluence segments.

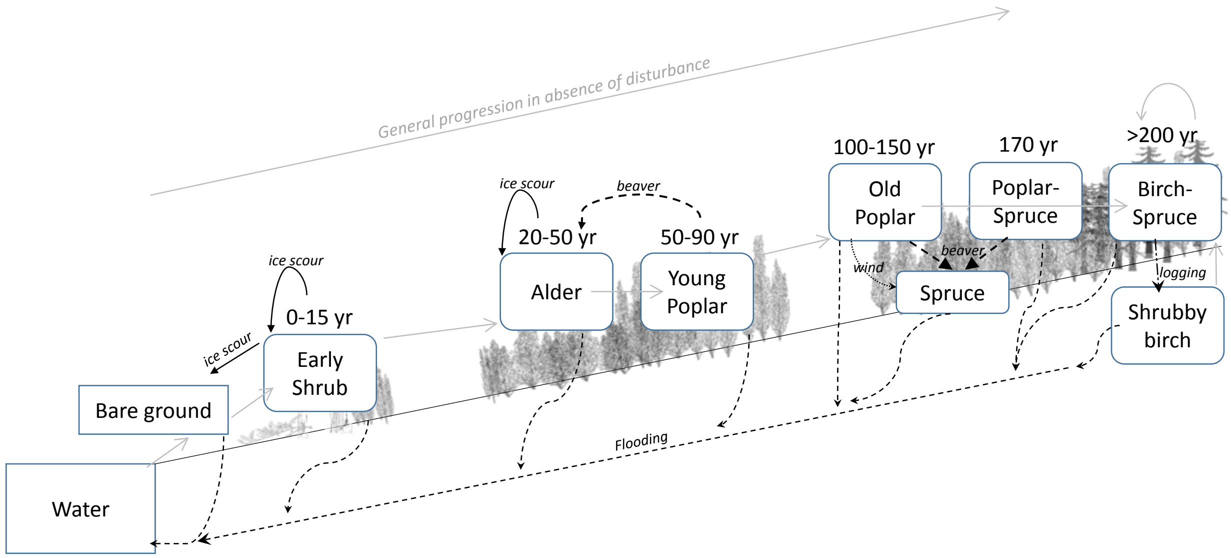


Figure 10. 1980s conceptual model of successional pathways along the Susitna River and their controlling factors. Flooding includes erosion and sedimentation. Years above diagram represent generalizations of when types may dominate. Adapted from Helm and Collins 1997.

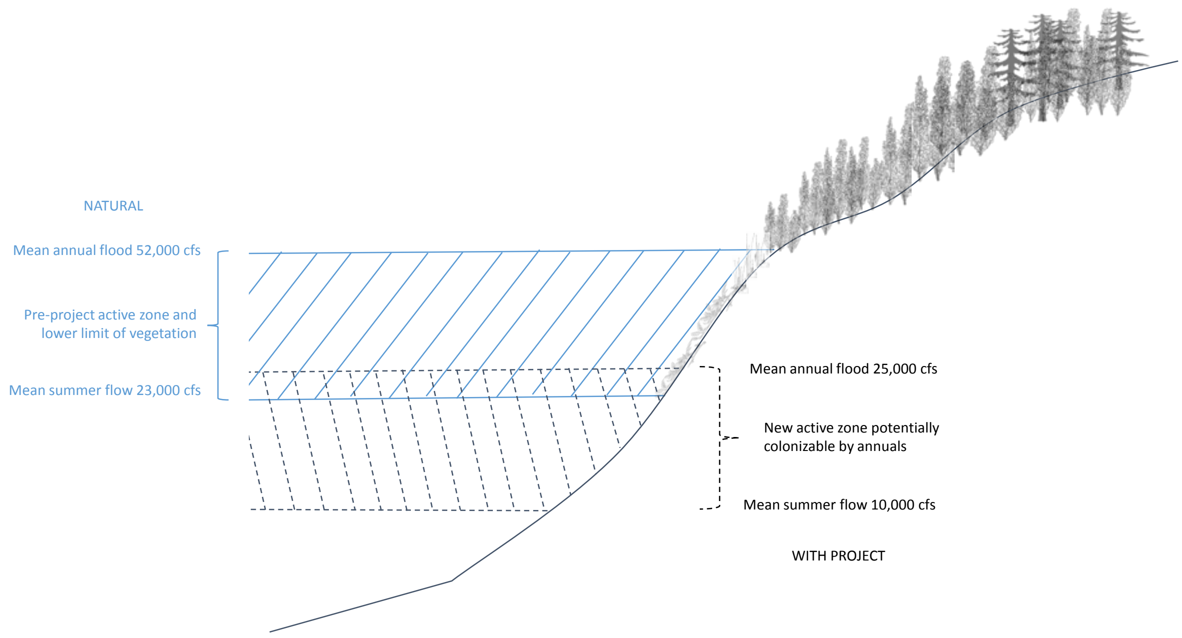


Figure 11. 1980s determination of natural and with project water levels and their implications for vegetation establishment.

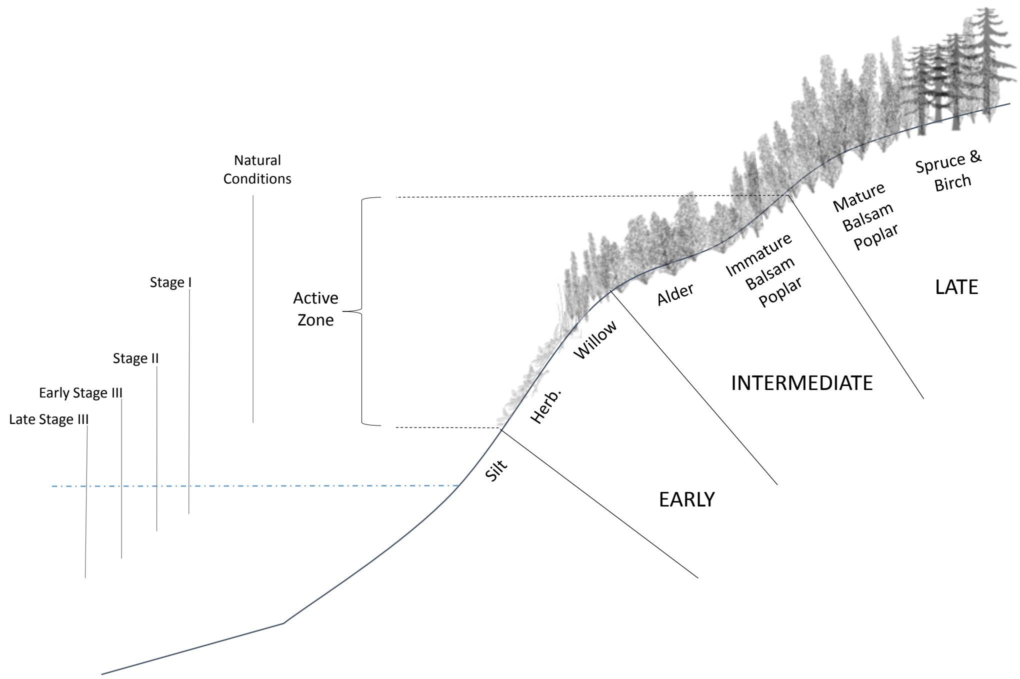


Figure 12. 1980s conceptual model of downstream vegetation impacts including changes in active zone with-project. Note that the active zone narrows as well as lowers in elevation with-project adapted from *SuWa Impacts Assessment Downstream Vegetation* (Harza-Ebasco 1985) (Figure 2).

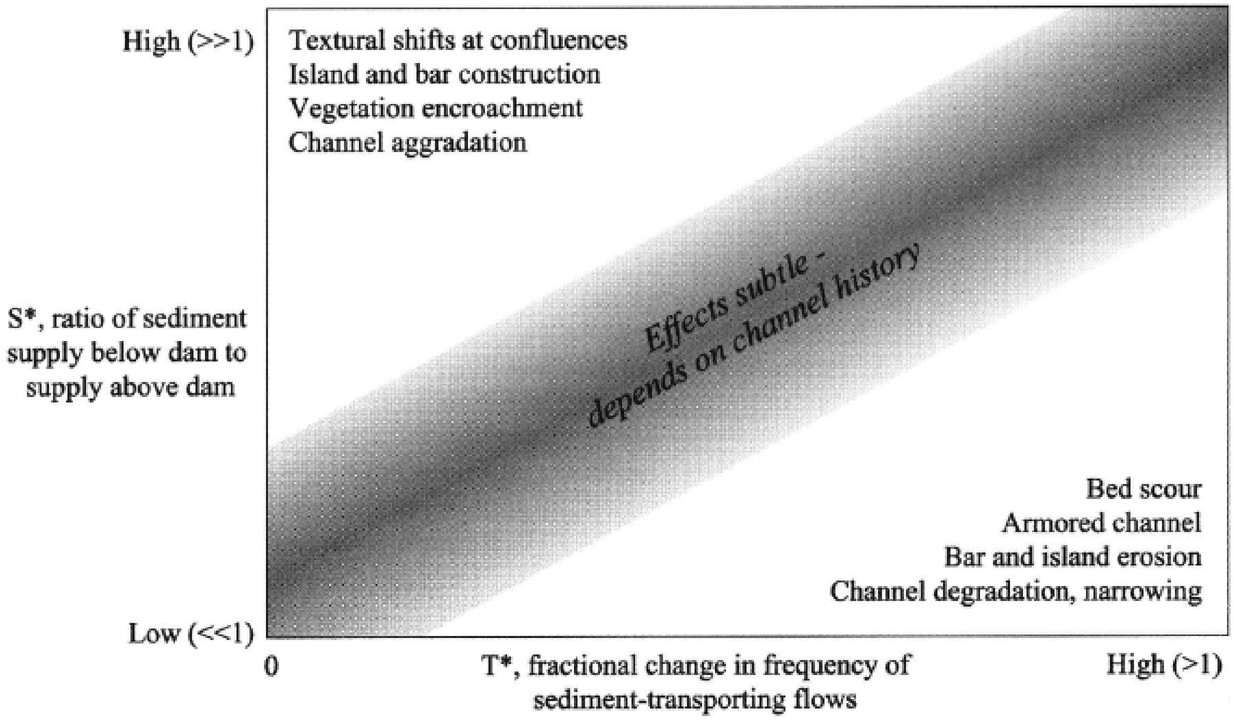


Figure 13. Response domain for predicted channel adjustments (Grant et al. 2003).

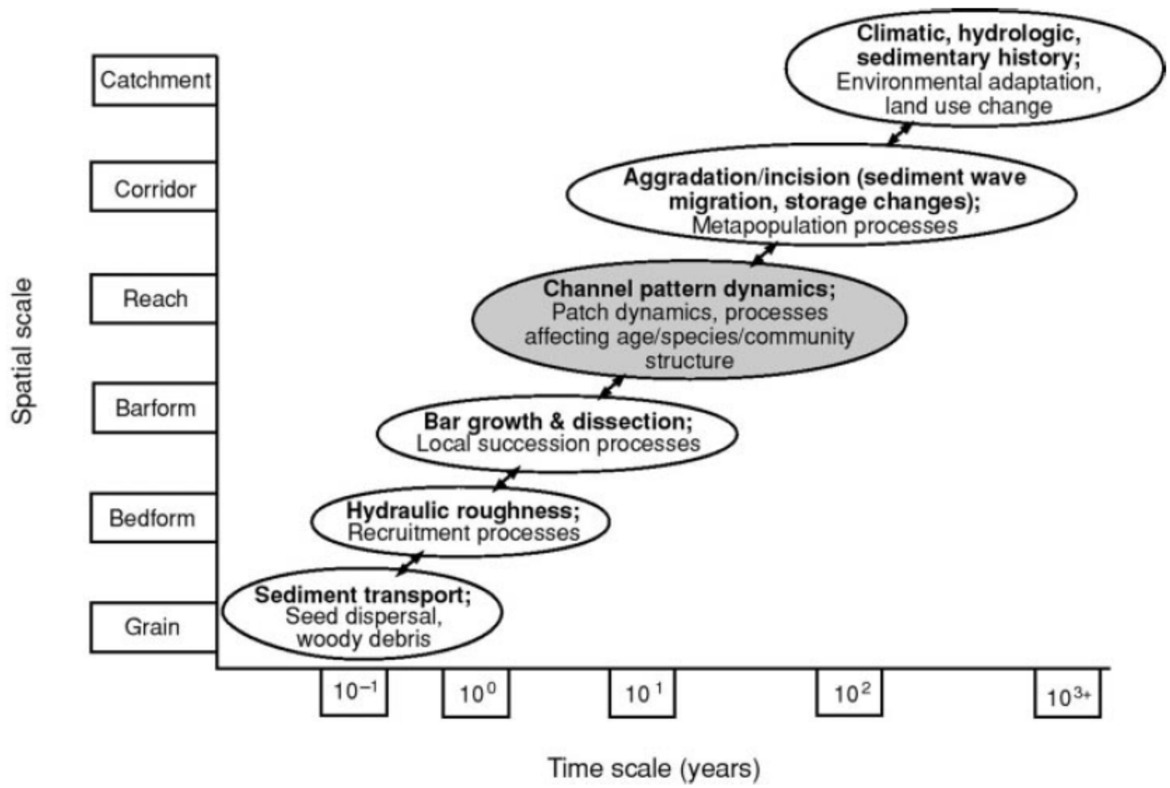


Figure 14. Hierarchical spatial and temporal relationships between fluvial (bold text) and ecological (normal text) processes (Richards et al. 2002).

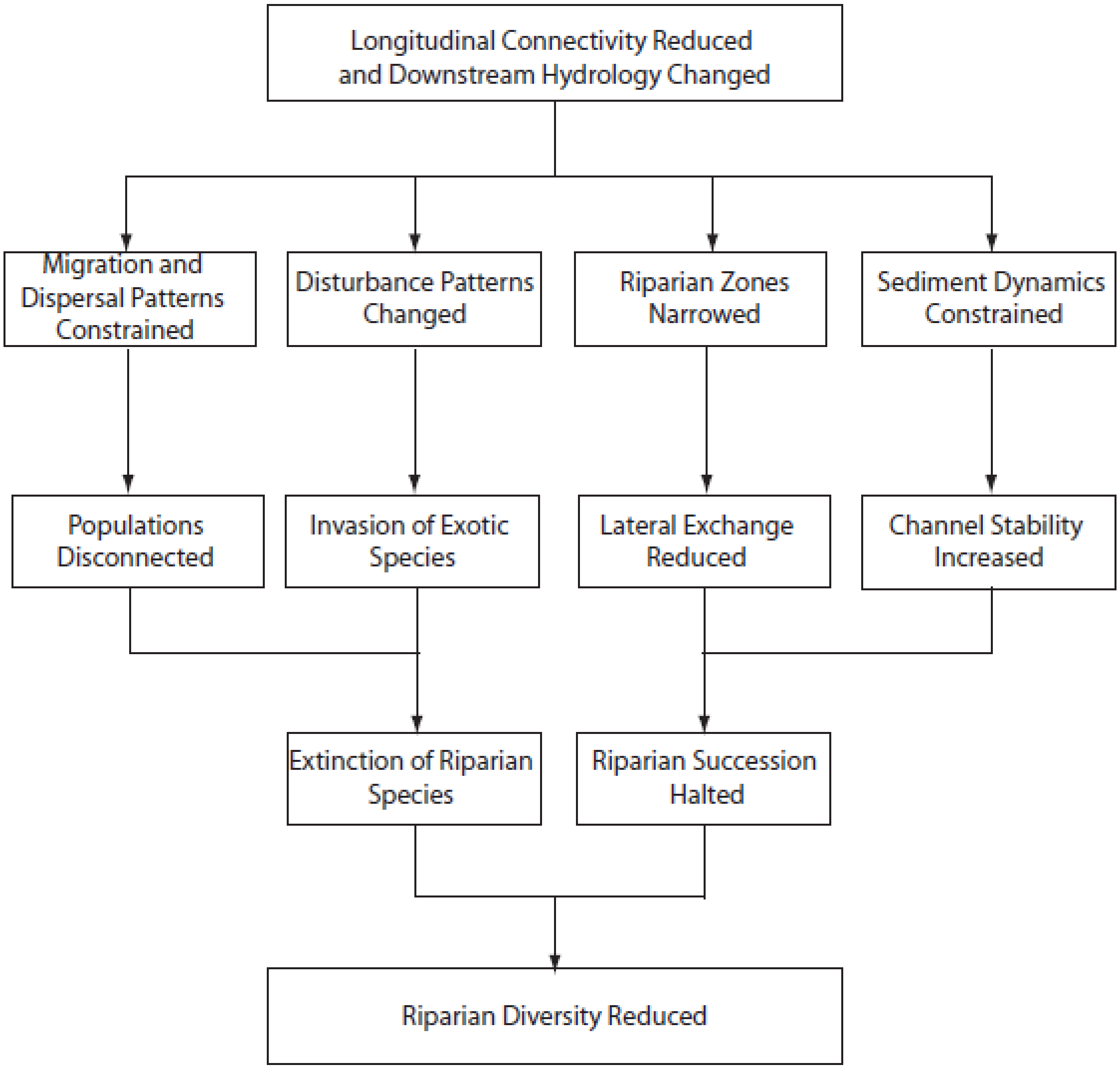


Figure 15. Overview of dam effects on riparian vegetation succession following reduction in peak flows and attendant flood regime (Nilsson and Berggren 2000).

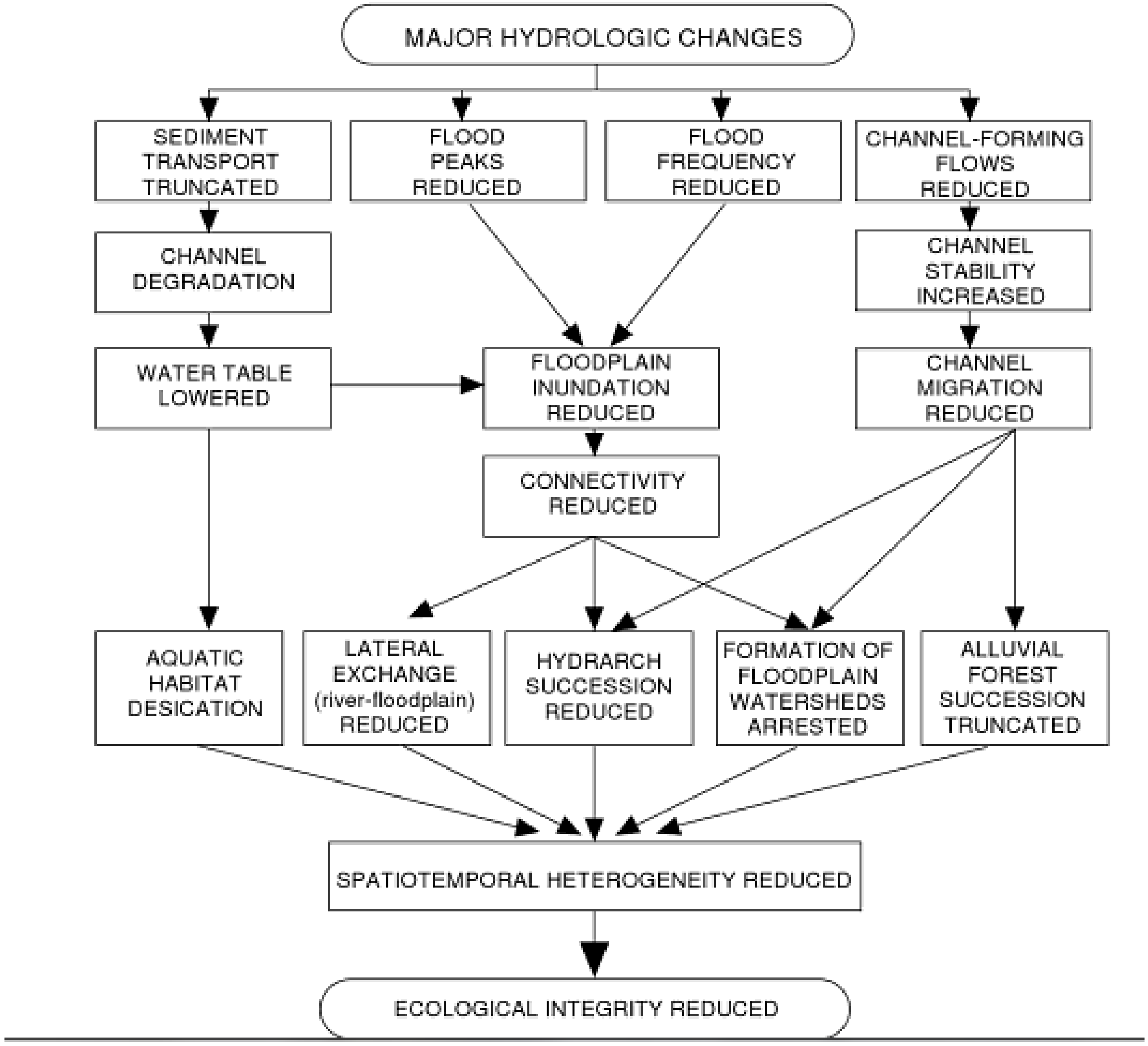


Figure 16. Ecological implications of major hydrological changes induced by flow regime regulation on downstream river-floodplain systems. (Naiman et al. 2005 ; after Ward and Stanford 1995).

APPENDIX A. ANNOTATED BIBLIOGRAPHY

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Adams, P.C. 1999. The dynamics of white spruce populations on a boreal river floodplain. Dissertation. Duke University, Durham, NC.	1999	Succession	Dissertation PhD	Interior Alaska - Tanana	Boreal	113,959 sq km	free-flowing	940 km	boreal floodplain, white spruce, establishment
Adams (1999) characterizes boreal floodplain white spruce forests and describes major environmental and biotic constraints on their development. Successful colonization was found to be episodic due to stochastic environmental factors such as silt deposition from flooding, seed production and dispersal patterns, and herbivory of seedlings by hare. Trees have a 10 to 12 year population cycle with autogenic processes contributing to recruitment success at each stage of succession. The study builds on Walker et al. (1986) to test whether spruce establishment is facilitated by earlier successional species or whether transition is primarily due to differences in species longevity. The spruce and poplar establishment ages and terrace ages were determined at more than 30 sites in the Tanana floodplain, and annual seed fall was measured. Adams found that white spruce seedling density was highly variable on early successional terraces but increased following years with high seed production. White spruce establishment was shown to be successful starting at 10 to 15 years after the initial establishment of willows on silt bars following years coinciding with high seed production. Bare mineral soil associated with flooding or windthrow are critical for establishment. The first generation of spruce was commonly observed to recruit over a relatively short period of time during the balsam poplar stage of succession.									
Alaska Power Authority. 1984. Alaska Power Authority Comments on the Federal Regulatory Commission Draft Environmental Impact Statement. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 1779.	1984	Ice Effects	White Paper Report	Susitna	Boreal	50,764 sq km	Free Flowing	504 km	None
APA (1984) presents results on the river ice simulations using ICECAL performed for the Susitna River with four different levels of energy demands and either the Watana project operating independently or the Watana and Devil Canyon projects operating simultaneously on the Susitna River. They utilize four different winters (two average temperature and two cold winters) to analyze simulation of water levels, mainly at Slough 8A, Slough 9, and Slough 21. Colder winters under natural conditions created more ice, raised water levels, and increased the distance the ice front progressed. In the case of Watana operation during average winter temperatures maximum water levels would be higher than under natural conditions but the leading ice edge might not progress upstream past Sloughs 8A, 9, and 21 as frequently, contributing to less slough berm overtopping. With Watana and Devil Canyon together, maximum water levels would be 1-4 feet lower than with Watana alone and either higher or lower at each slough depending on location. With colder winters, water levels with Watana operating alone and with Watana and Devil Canyon together, water levels would be higher and more frequent overtopping of Slough 8A and 9 would occur. The remainder of this paper presents figures from simulations.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Amlin, N.M. and S.B. Rood. 2002. Comparative tolerances of riparian willows and cottonwoods to water-table decline. Wetlands 22(2): 338-346.	2002	Seedling Recruitment	Peer Reviewed Basic Research	Western U.S.	Semi-arid				drought, growth, mortality, *Populus*, recruitment, *Salix*, saplings, seedlings, survival, watertable decline
Amlin and Rood (2002) experimentally manipulated water table declines and determined the effects on plant growth and survival of *Populus balsamifera, Populus deltoides, Salix exigua*, and *Salix lutea*. They performed a sapling and a seedling study in rhizopods using six different levels of water table decline. For saplings they found that all species increased root elongation with a gradual water table decline of 1 and 2 cm/day, over this root length was reduced in all species. *S. exigua* had the greatest root elongation at gradual rates of decline, showing increased tolerance to an anaerobic environment, while P. balsamifera had the greatest elongation at rapid rates of decline showing a greater drought tolerance. In the seedling study, survival was significantly impacted by the rate of water table decline. However, P. balsamifera seedlings recruited under all treatments while S. exigua only under 0 and 1 cm/day declines. These results show that in general a gradual water table decline promotes root and shoot growth, while rapid declines reduce growth and increase mortality. The authors then used these results to refine the "Recruitment Box Model" developed by Mahoney and Rood (1998) for these particular species. They discussed how different water table decline rates are necessary for recruitment of different species and how mimicking a natural hydrograph on regulated rivers would promote establishment of a variety of native riparian plants.									
Andersson, E., C. Nilsson, and M.E. Johansson. 2000. Plant dispersal in boreal rivers and its relation to the diversity of riparian flora. Journal of Biogeography 26: 1095-1106.	2000	Seed dispersal and establishment	Peer Reviewed Basic Research	Northcentral Sweden (Vindel and Ume Rivers)	Boreal		Free flowing and dammed	348 km and 9 km (sections studied)	Diaspore mimics, hydrochory, riparian corridor, plant dispersal, Vindel River
Andersson et al. (2000) researched the use of diaspore mimics (wooden blocks) to understand seed dispersal dynamics, floating time, and riparian vegetation patterns along the unregulated Vindel River in Sweden. They found wooden blocks to be usable as diaspore mimics since upon release with *Helianthus* achenes they were deposited in mainly the same areas. Even though the floating time of blocks and seeds was dramatically different it did not result in differential dispersal because seasonal floodwaters move so quickly in free flowing rivers. Therefore, seeds of many different floating times would likely disperse quickly and to similar areas. The authors found that the presence of rapid current was the only environmental variable to predict the differences in the number of cubes deposited along the river. At areas with high numbers of deposited cubes, total species richness was significantly higher than in areas with lower numbers of cubes. These areas appeared to be places along the riverbank that consistently receive a lot of drift material. However, the number of deposited cubes did not predict the number of seedlings. Number of seedlings was only correlated with the availability of bare ground. Therefore, it was concluded there are multiple complex interactions that occur between seed dispersal and seedling establishment. A related study released blocks on a regulated stretch of the Ume River, and the authors concluded from this that floating time is more critical for dispersal on regulated than unregulated rivers due to the slower flow rates.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Angradi, Ted R., E. William Schweiger, David W. Bolgrien, Peter Ismert, and Tony Selle. 2004. Bank stabilization, riparian land use and the distribution of large woody debris in a regulated reach of the upper Missouri River, North Dakota, USA. River Research and Applications 20, no. 7: 829-846. http://doi.wiley.com/10.1002/rra.797.	2004	Association of LWD and riparian land-use	Peer reviewed Basic Research	upper Missouri River, North Dakota	temperate	482,774 km^2	reservoir storage system	Approximately 160 km	large woody debris, snags, Missouri River ecosystem, flow regulation, bank stabilization, riparian, riprap
Angradi et al. (2004) examined Large Woody Debris (LWD) on a regulated river reach (Garrison Reach) of the Upper Missouri River in North Dakota. Through shoreline surveys of LWD over two summers during typical summer flow conditions, LWD was quantified by density based on shoreline type (i.e., stable and unstable alluvial (sand/silt), forested, open (e.g., rangeland, crop land) and developed (e.g., residential, industrial)). Effects of shoreline type and riparian land use, effects of channel location, and intra- and interannual variation were analyzed against LWD density and type. The study concluded that bank stabilization reduced local density of shoreline-associated LWD. Further, LWD density was about 3.5 times higher along unstabilized shorelines than along stabilized shorelines, 4-5 times higher along forested shorelines than open or developed shorelines, and overall highest along unstabilized forest shorelines. Pre-regulation distribution of LWD in the Garrison Reach and the effects of decay or ice jamming on LWD were not evaluated in depth in this study. In summary, river ecosystem management that evaluates LWD and the connection between biotic (i.e., riparian) and hydrologic interactions is presented.									
Anselmetti, Flavio S, Raphael Bühler, David Finger, Stéphanie Girardclos, Andy Lancini, Christian Rellstab, and Mike Sturm. 2007. Effects of Alpine hydropower dams on particle transport and lacustrine sedimentation. Aquatic Sciences 69, no. 2: 179-198.	2006	Dam effects on particle transport and lacustrine sedimentation	Peer reviewed Basic Research	Aare River, Switzerland	temperate	6,865 square miles (17,779 square km)	hydroelectric	183 miles (295 km)	sediment yield, reservoir lakes, lacustrine sedimentation, particle transport, erosion rates
Through modeling of particle budgets on the River Aare, Anselmetti et al. (2007) evaluate the effects of damming on lacustrine sedimentation and particle transport. River Aare is located within a glaciated region and drains into Lake Brienz. Reservoirs on River Aare have been accumulating sediment for over 75 years and reducing the total sediment load into the lake by two thirds. Results indicate that fine sediment fractions within the reservoir deltas are only partially affected by damming. Damming was found to predominantly effect sedimentation of Lake Brienz's delta due to the higher trap efficiency of course sediment that builds deltas. Varved records (annual layer of sediment) within the reservoirs and in Lake Brienz indicate climate is the primary control of fine-grained sedimentation.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Arctic Environmental Information and Data Center. 1984. Assessment of the effects of with-project instream temperatures on Susitna River ice processes in the Devil Canyon to Talkeetna reach. Alaska Power Authority. Susitna Hydroelectric Project. Draft Report.	1984	Ice Processes	White Paper Report	Susitna	Boreal	50,764 sq km	Free Flowing	504 km	None
Arctic Environmental Information and Data Center (1984) described natural ice processes over several years prior to 1984 and used the model ICECAL to simulate how ice processes would occur under several different operation scenarios of the proposed 1980s Susitna hydroelectric project. The author first described the natural processes and provided historic ice records for the lower, middle, and upper Susitna river in terms of ice generation, the peak of ice development, and ice breakup. He then used the ICECAL model to predict changes during these three periods of ice processes. Since dam output waters would be warmer than usual, freeze up would be delayed on the Susitna anywhere from 2-6 weeks depending upon operation scenario. There would be a portion of river, beginning anywhere from river mile 123 to 142 up to the dam sites that would remain unfrozen all year. Ice thickness would either remain similar to natural conditions or be 1-2 feet less thick depending upon operation scenario. Finally, breakup would change dramatically, it was predicted to occur anywhere from 4-8 weeks earlier and a slower melt out of ice cover would occur in place.									
Arctic Environmental Information and Data Center. 1985. Geomorphic change in the middle Susitna River since 1949. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 2827.	1985	River Geomorphology	White Paper Report	Susitna	Boreal	50,764 sq km	Free Flowing	504 km	None
Arctic Environmental Information and Data Center (1985) used aerial photography analysis from 1949 to 1984 to determine changes in Susitna River geomorphology. They found that along the middle river, gravel bars and islands became more exposed and vegetation was becoming more established on them, and succession of plant communities was occurring. They found eight places in the middle river mainstem channel where the river had shifted alignment progressively over this period. Sloughs throughout the river had mainly changed from side channels to side sloughs or from side sloughs to upland sloughs during this time. All of these pointed to a general degradation of the Susitna which the authors stated has been occurring since around 10,000 years ago. They evaluated the effects of two major catastrophes on the river. The 1952 Susitna Glacier surge was determined to have increased some sediment discharge but an increase in flows was unsubstantiated. However, the 1964 earthquake tilted the river southward by approximately 1.5 feet over 320 river. Since the upper river runs parallel to this tilt, degradation here would have been more substantial than in the middle or lower river, but it was not investigated. Finally, construction of the Susitna Hydroelectric Project was hypothesized to accelerate scouring of the river bed initially by about 1-1.5 feet, though this would taper off and an armor layer would develop and stabilize the riverbed so that long term natural degradation of the river would decrease. The authors thought this would stop the natural changes in sloughs and result in a stable fish habitat in these areas. They cautioned that although fish habitat would be stable, it may not necessarily remain suitable.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Arthington, A.H., S.E. Bunn, N.L. Poff, and R.J. Naiman. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16(4): 1311-1318.	2006	Natural Flow Regimes	Peer Reviewed Basis Research						benchmarking; classification; flow-ecological relationships; flow variability; natural flow regime paradigm; river ecosystem condition
Arthington et al. (2006) work to develop, and eventually implement a scientifically credible regional flow guideline for the restoration and protection of the ecological integrity of streams. The authors propose a generic four-step approach for the assessment and restoration prescription of the natural flow regime to managed rivers, incorporating essential aspects of flow variability shared across particular classes of rivers that can be validated with empirical biological and hydrologic data in the calibration process. The classification approach proposed is: (1) develop a hydrologic classification from reference streams, which entails finding near-by streams that have natural flow regimes to scale the restoration effort for hydrologic characteristics, (2) for each class, develop frequency distributions for selected hydrologic variables, (3) compare frequency distributions from flow-modified streams with reference conditions in the same class, and (4) develop flow response relationships for the ecological health data from reference and flow modified streams for each flow variable.									
Assani, Ali a, Raphaëlle Landry, Jonathan Daigle, and Alain Chalifour. 2011. Comparison of the interannual and interdecadal variability of heavy flood characteristics upstream and downstream from dams in inversed hydrologic regime: Case Study of Matawin River (Québec, Canada). Water Resources Management 25, no. 25: 3661-3675.	2011	Dam effect on hydrologic regime	Peer reviewed Basic Research	Matawin River, Québec	Boreal	5775 km^2	hydroelectric		reservoir, inversion, floods, downstream effects, seasons, climate indices, Matawin River, Québec
Through an evaluation of the hydrologic regime of the Matawin River in Québec, Canada, Assani et al. (2011) determined variance in flood characteristics upstream and downstream from the Matawin Dam. As with many hydroelectric projects, damming of the Matawin River led to an inversion of the hydrologic regime by the storage of snow melt runoff in spring and subsequent release of high flow in winter for energy production. Through an interannual and interdecadal comparison of the magnitude, duration, frequency and variability of floods that occurred upstream and downstream from the point of regulation, modified flood characteristics have been quantified. Results indicate a significant increase in the duration of large floods downstream of regulation which corresponds to a reduction in magnitude, frequency, and variation of flooding. The Atlantic multidecadal oscillation (AMO) and increased hydropower production are two causes found to explain increased duration in flood flows.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Auble, G.T. and M.L. Scott. 1998. Fluvial disturbance patches and cottonwood recruitment along the Upper Missouri River, Montana. Wetlands 18(4): 546-556.	1998	Seedling establishment	Peer Reviewed Basic Research	Missouri River, Montana, USA	Semi-arid		Dammed	172 km reach	dam, flood, livestock grazing, hydrogeomorphic, ice, *Populus deltoides,* riparian, seedling demography, streamflow
Auble and Scott (1998) observed seedling establishment along the Wild and Scenic reach of the Missouri River to investigate how cottonwood recruitment depends upon flood regime. They also looked at how cattle grazing influences cottonwood recruitment in this same region through use of grazing exclosures. Overall, new seedlings were found mainly in the area between the high and low water marks (from flow during May 15 to September 1) and there were fewer seedlings at grazed sites. Scott et al. (1996) developed the hydrogeomorphic recruitment model which discussed three ways that rivers provide the necessary disturbance and moisture conditions for seedling recruitment: channel narrowing, channel meandering, and flood deposition. On this river reach the authors determined that flood deposition was the main recruitment mode for cottonwood trees, and most trees were established during 9-10 year floods. They also discussed how ice increased seedling mortality for those seedlings established in areas that are flooded at low flows. However, the dams on this river have resulted in a lower peak discharge and decreased flood frequency and thus decreased the size of the zone that is inundated at the correct frequency for successful seedling establishment and also above the ice disturbance zone. Finally, they discussed how channel meandering, alternative influences of livestock grazing, and ideal climatic conditions may additionally contribute to successful seedling establishment on this river by providing bare, moist sites.									
Auble, G.T., J.M. Friedman, and M.L. Scott. 1994. Relating riparian vegetation to present and future streamflows. Ecological Applications 4(3): 544-554.	1994	Riparian Response to Flow Alteration	Peer Reviewed Basic Research	Gunnison River, Colorado, USA	Semi-arid	10,000 sq km	Dammed		bottomland vegetation; dam; discharge; diversion; environmental impact; flow duration; Gunnison; hydraulic model; riparian vegetation; TWINSPAN; vegetation change.
Auble et al. (1994) predicted the response of riparian vegetation to changes in discharge on the Gunnison River in Colorado using a direct gradient analysis. All plant species were grouped into three classes based upon inundation duration, cover, and soil particle size: *Heterotheca*, *Equiestum*, and *Eleocharis* cover types. Heterotheca is the driest cover type with the lowest percent of vegetative cover, while Eleocharis is the wettest with the highest percent of vegetative cover. Three alternative hydraulic regimes from the Reference regime were analyzed: Diversion, Diversion-Increased-Minimum, and Moving-Average. With the Diversion regime, the mean flow would be decreased to 54% of the Reference mean flow and some of the Eleocharis vegetation type is converted to Equisetum while a greater portion of Equisetum is changed to Heterotheca. With the Diversion-Increased-Minimum flow the mean flow is 64% of the Reference flow and Eleocharis also decreases. For the Moving-Average flow regime, the mean flows are unchanged from the Reference regime but Heterotheca and open water cover both increase. Overall, it appears that as extreme flows are moderated, inundation duration increases where it is already high and decreases where it is already low. This decrease in flow variation also leads to an increase in extreme cover types (dry and wet). Even when the mean flow is unchanged, large changes can occur in riparian vegetation cover. This type of model created a single measure of vegetation response to changes in flow and this could be useful when riparian vegetation response is simply one factor in water management decisions. However, there are inherent problems with simplifying vegetation response so greatly and it may make information difficult to transfer between sites.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Auble, G.T., M.L. Scott, and J.M. Friedman, 2005. Use of individualistic streamflow-vegetation relations along the Fremont River, Utah, USA to assess impacts of flow alteration on wetland and riparian areas. Wetlands 25(1): 143-154.	2005	Riparian Response to Flow Alteration	Peer Reviewed Basic Research	Fremont River, Utah, USA	Arid	5,025 sq km		153 km	instream flow, hydraulic modeling, downstream impact assessment, wetland delineation, moisture gradient, riparian vegetation plant communities
Auble et al. (2005) developed a model utilizing state-discharge from a hydraulic model to generate flow-duration curves to calculate the inundation duration of sample plots. Inundation duration was compared to plant species occurrence using logistic regression to characterize plots as aquatic, wetland, terrestrial or upland through the use of a weighted average of the wetland indicator species. The relationships developed in the stage-discharge and flow-duration curves can be used to estimate changes in flow from regulation, and the subsequent effects on the patterning of riparian vegetation. The model corroborated the generally accepted rule that inundation of two weeks out of two years gives rise to a wetland vegetation regime. The remainder of the paper discusses the assumptions and potential limitations of the model, such as the model's assumption that the development of these riparian patterns formed under equilibrium with the flow regime. There is also discussion whether this model for wetlands can be used in riparian zones that have much greater extents.									
Auble, G.T., M.L. Scott, J.M. Friedman, J. Back, and V.J. Lee. 1997. Constraints on establishment of plains cottonwood in an urban riparian preserve. Wetlands 17(1): 138-148.	1997	Seedling establishment	Peer Reviewed Basis Research	Boulder Creek, Colorado	Semi-arid	376 sq km	Dammed and manipulated		channel change, channel stabilization, cottonwood, dam, disturbance, flood, flow regulation, riparian, urban floodplain
Auble et al. (1997) investigated seedling establishment along Boulder Creek in Colorado which has been dammed and also subjected to channel manipulation since the mid 1800s including channelization, diversion, straightening, clearing, and stabilization. Terrace sites along the river were found to have very few old cottonwood trees (established from 1906-1924) and many nonnative saplings. No cottonwood seedlings or saplings were present on terraces. On floodplain sites sandbar willow, green ash, and crack willow as well as cottonwood seedlings (in 1990) were found at sites that were inundated by discharges below 15 m^3/s, while Russian olive was found at sites inundated by <1 m^3/s. Older cottonwood saplings were found at sites inundated by 15-31 m^3/s discharges and were established in 1983, 1984, and 1987. Additionally, from 1937 to 1992 vegetation has encroached into the open areas near the creek channel. Overall, this data shows cottonwood establishment is limited to moist and bare sites that are created via scouring flows and then remain safe from future disturbance. Due to the reduction of flood peaks, channel clearing, and possible downcutting there has been a decrease in the area that is disturbed by the stream and therefore less of an area for cottonwood establishment. Species that succeed in low, moist sites like Russian olive, or species that can reproduce vegetatively with widespread success (sandbar willow, crack willow, and green ash) appear to benefit from regulation and stream modifications. Additionally, the terrace zone is now completely decoupled from riverine disturbance and as cottonwood establishment has decreased, exotic species have proliferated on terraces. Finally the authors present thoughts on how to manage this system to increase cottonwood establishment and also state it is important to recognize the importance of natural stream physical processes like bank erosion, shifting channels, sediment transport, and overbank flooding.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Auble, G.T., P.B. Shafroth, M.L. Scott, and J.E. Roelle. 2007. Early vegetation development on an exposed reservoir: Implications for dam removal. Environmental Management 39: 806-818.	2007	Dam removal and vegetation succession	Peer Reviewed Basis Research	Horsetooth Reservoir, Colorado River	Semi-arid		Dammed		Colorado, Cottonwood, Dam removal, Drawdown, Horsetooth Reservoir, Recruitment box model, Reservoir margin, Riparian
Auble et al. (2007) studied vegetation colonization and succession after the lowering of a reservoir pool during a four year period of dam maintenance at the Horsetooth Reservoir along the Colorado River. Four sections of land were analyzed since the reservoir was lowered during four successive years and the percentage of native plants, percentage perennial plants, percent cover, and wetland status were analyzed. Native plants decreased over time since inundation, cover ranged from around 21-36% for the first year inundated and then decreased for the middle two years, and then reached a maximum of 37-59% after four years, wetland indictor values increased over time (site became drier) since exposure, species richness peaked in the two-three years since inundation, and perennials increased throughout time since exposure. Plains cottonwoods were the main tree that colonized recently exposed surfaces. They preferred the zone near the water's edge where they began to establish following the seed release period, from June 1 to July 7 each year, and they grew with reservoir decline rates from 4-8cm/day which is more rapid than the decline rate predicted by the Recruitment Box Model of 2.5 cm/day. They were also able to persist at elevations from 7-19m above the water level, much higher than the general 60-200cm observed by other researchers. This is likely due to the local variance in substrate particle size, capillary rise, local subsurface drainage, and wave action. These observations have important implications for dam removal and post removal reservoir management. Topography, substrate characteristics, pre-dam vegetation, and the current vegetative community in the area should all be considered during dam removal. Weed control will need to be maintained over many years and the rapidly changing site conditions must be incorporated in any management actions. Finally, the authors state that dam removal should be viewed as a new disturbance and not just the simple reversal of an old disturbance.									
Ayles, C.P. and Michael Church. Downstream Channel Gradation in the Regulated Peace River. In The regulation of Peace River. ms. Edited by Michael Church. In preparation.	In preparati on	Dam Effect on Channel Gradation	Chapter in Book	Peace River, British Columbia and Alberta	Boreal		hydroelectric	1250 km	fluvial aggradation, fluvial degradation, regulated river, river gradation, specific gauge
Ayles and Church, in The Regulation of Peace River (book in preparation) identify the morphological evolution in the downstream channel of Peace River (British Columbia and Alberta) from the point of regulation. More specifically, the vertical gradation of the channel in the 147 km reach downstream of Bennett Dam is quantitatively assessed through repeated cross-sectional surveys. The hydrologic regime has been significantly affected with peak flow reduction while the sediment regime has remained relatively similar to the pre-regulation regime. Results of this study reveal limited and localized degradation in the 147 km studied reach largely due to the removal of bed-mobilizing flows. Aggradation was found at tributary confluences and below sediment sources. Overall, the river profile is becoming stepped. Study results also indicate that the Peace River may complete channel adjustments within the next 50 to 100 years as opposed to previously predicted time estimates of up to 1000 years. However, in some locations, continued aggradation from recent flooding may be beginning the slow processes of aggradation progressing downstream from sediment sources in the upper river. These results contrast common downstream effects of dams where the channel is largely degradational.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Ayles, C.P. and Michael Church. Tributary Gradation due to Regulation of Peace River. In The regulation of Peace River. ms. Edited by Michael Church.	In preparation	Dam Effect on Tributary Gradation	Chapter in Book	Peace River, British Columbia and Alberta	Boreal		hydroelectric	1250 km	floodplain, regulated rivers, river degradation, tributary gradation
Ayles and Church, in The Regulation of Peace River (book in preparation), evaluate changes in tributary gradation due to flow regulation on Peace River through a series of cross-sectional surveys, dendrodating and field observations. Often times damming leads to main channel degradation and a corresponding upstream-progression of tributary channel degradation. This study attempts to quantify the magnitude, upstream extent and spatial occurrence of tributary degradation. The 143 km reach immediately downstream of the dams comprises the study area. Results indicate that base level lowering in tributaries is occurring. Downstream of Pine River, the first major tributary downstream of regulation, effects of regulation are not as apparent due to the influx of flow and sediment from other tributaries and main channel ice-regime. Excluding one tributary, the mean gradation of tributaries above Kiskatinaw River is about – 0.9 meters.									
Baird, K.J., J.C. Stromberg, and T. Maddock, III. 2005. Linking riparian dynamics and groundwater: ecohydrologic approach to modeling groundwater and riparian vegetation. Environmental Management 36(4): 551-564.	2005	Riparian and Groundwater Modeling	Peer Reviewed Basis Research	South Fork Kern River, California; Unnamed Basin, Arizona, USA	Semi-Arid and Arid				Riparian evapotranspiration; Ecohydrologic model; Groundwater; plant functional group; MODFLOW
Baird et al. (2005) are the authors of the RIP-ET model, and discuss the methodology and increased accuracy with the new technique developed for the model. The RIP-ET model develops the interaction between groundwater and riparian vegetation in five manners that are considered more realistic beyond the traditional linear and segmented function of MODFLOW, (1) incorporation of functional groups, (2) more realistic shape of the ET flux rate related to depth, (3) multiple flux rate curves per modeling cell, (4) fractional species coverage by cell, and (5) the incorporation of land surface elevation. The development of the RIP-ET model has reduced misrepresented ET demands varying from ~500% to 37% of actual demands in comparison to the linear segmented functions of MODFLOW. The methodology incorporates a larger spatial dataset through the use of GIS, and with the assistance of the spatial component, more accurate models such as the "Recruitment Box Model," can more accurately predict recruitment and success.									
Bang, A., C Nilsson, and S. Holm. 2007. The potential role of tributaries as seed sources to an impoundment in Northern Sweden: a field experiment with seed mimics. River Research and Applications 23, no. 10: 1049-1057.	2007	Tributary effects on regulated rivers	Peer reviewed Basic Research	Ume River, Sweden	Boreal		hydroelectric, reservoirs		fragmentation, hydrochory, plant dispersal, impoundment, seed mimics, Ume River, Sweden
Bang, Nilsson and Holm analyzed the effect of free-flowing tributaries as seed sources to a run-of-river impoundment on the Ume River, Sweden. Through the release of seed mimics on three tributaries upstream of the impoundment outlet, seed dispersal capacity was evaluated. The study found the majority of seed mimics to remain close to the initial release point. A small percentage (1.5 %) of seeds was found to travel into the impoundment with the largest tributary comprising the majority of this population. Because even one seed from a population can be sufficient to offset species depletion, the small percentage of seed mimics that travelled longer distances is considered sufficient to maintain species dispersal due to regulation. The study concludes that tributaries have the capacity to mitigate fragmentation of seed dispersal (and corresponding species richness and diversity) due to river regulation.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Barsoum, N. 2002. Relative contributions of sexual and asexual regeneration strategies in *Populus nigra* and *Salix alba* during the first years of establishment on a braided gravel bed river. Evolutionary Ecology 15: 255-279.	2002	Cottonwood and Willow Reproduction	Peer Reviewed Basic Research	Southeast France, Drome River	Temperate				clonal vs. sexual recruitment, flood disturbance, floodplain woodland, microsites, Populus nigra, regeneration, river, Salicaceae, *Salix alba*, spatial pattern
Barsoum (2002) studied the differences in patterns of abundance and distribution of *Populus nigra* and *Salix alba* sexual and asexual recruits along the Drome River in France. She also wished to evaluate how changes in flood conditions could affect the balance between and distribution of these two different reproduction strategies. Seedling numbers far outweighed vegetative recruits during the first year of establishment, however by the fourth year these two types of recruits were similar in numbers. Seedlings were found mostly at low elevations, with *S. alba* lower than *P. nigra*, and in fewer numbers. At low elevations, *P. nigra* seedlings were found at gravel bar, sand bar, and sediment filled depressions and also at high elevation sediment filled depression microsites. At low elevations *S. alba* seedlings were mainly at sediment filled depressions and along the edges of side channels, and also at depressions at high elevations. Four types of vegetative reproduction were described: flood training, translocated fragments, coppice re-growth, and suckering. Translocated fragments were the most common type of reproduction, and suckering the most rare. The role of beavers in initiating vegetative reproduction, especially with *S. alba*, was widespread. Vegetative *P. nigra* recruits were much more scattered and at a wider variety of microsites, more often at higher elevations. *S. alba* vegetative recruits were mostly at high elevations near woody debris. Overall, seedlings depended initially upon microsite availability for establishment, but then, similarly to vegetative recruits, survival and development depended on river flow. *S. alba* seedlings appeared to be more vulnerable to flood disturbances than *P. nigra* seedlings, but seedlings in general had reduced survival compared to vegetative recruits. The author stated that changes in flow conditions could be most detrimental to sexual reproduction, and called for a genetics based study to determine how different flood and sediment delivery regimes would affect diversity as a result of decreased sexual reproduction.									
Bednarek, A.T. 2001. Undamming rivers: a review of the ecological impacts of dam removal. Environmental Management 27(6): 803-814.	2001	Dam removal	Literature Review	United States			Dam removal		riparian vegetation, river, shrubs, trees
Bednarek (2001) investigated the possible long and short term ecological impacts of dam removal by presenting several case studies. At this time (1999-2001) over 450 dams were slotted for relicensing with FERC, and were required to meet new operating standards. Therefore, this article discussed potential mitigations, in addition to dam removal, to remedy negative dam effects. Bednarek presented long term effects of dam removal (and mitigation) including: 1) adjusting or restoring natural flow conditions, 2) changing from a reservoir to a free-flowing river, 3) modifying water release or removal of reservoir stratification to permit natural water temperatures downriver, 4) increasing sediment and rocky substrate downstream, and 5) increasing connectivity of the whole river system. With each effect, the author focused mainly on how fish and fish habitat would be impacted but also mentioned impacts on riparian communities and physical processes. Bednarek also gave three short term effects of dam removal that would occur during the removal process: increased sediment release, potential release of contaminated sediment, and possible super saturation of dissolved oxygen. Throughout, case studies were presented from previous dam removals and benefits were made clear. Finally, the author discussed the need to characterize the ecosystem prior to dam removal so that effects can be understood after removal occurs and cautioned that dam removal is still poorly understood and can be controversial.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Bejarano Carrion, M.D., M.M. Sacristan, M.G. Del Tanago, D.G. De Jalon, and A. Sordo-Ward. 2012. Riparian guild composition changes along a regulated Mediterranean stream in central-western Spain. Ninth International Symposium on Ecohydraulics. Vienna, Austria, 2012.	2012	riparian vegetation-flow response guilds	Peer Reviewed Basic Research	Spain	Semi-arid	4478 sq km	Agriculture dam	150 km	dam effects, species life history, guild
Bejarano et al. (2012) clustered riparian species along the Tietar River in Spain into guilds using clustering techniques and ordination analysis and then evaluated changes in guilds following dam construction in 1959. Based on 20 variables associated with species life history, phenology, reproduction, morphology and ecology, 9 different guilds were grouped and named according to drought resistance, drag resistance, and flood resistance. Three of the guilds were not present pre-dam: Xeric/Torrential, Mesic/Torrential, and Semi-Torrential, while two guilds decreased in number following dam construction: Hydric/Slow-water/Flood-tolerant and Xeric/Slow-water/Flood-sensitive. Guilds appeared to respond to four main environmental factors: flood inundation, moisture, canopy, and substrate grain size. These guild shifts appear to be related to the decrease in discharge and flooding due to river damming. Use of indicator guilds instead of indicator species allows for ease of interpretation of environmental changes due to flow regulation and also generalization and comparison between different river systems.									
Bejarano, M.D. and A. Sordo-Ward. 2011. Riparian woodland encroachment following flow regulation: a comparative study of Mediterranean and Boreal streams. Knowledge and Management of Aquatic Ecosystems 402: 20.	2011	Vegetation encroachment following dam closure	Peer Reviewed Basic Research	Tiétar = Central-western Spain, Vojmån = Southern Lapland, Sweden	Boreal and Mediterranea n	Tiétar = 4478 sq km; Vojmån = 3543 sq km	Tiétar = Irrigation with Pluvia flow regime (Winter and spring peaks)/ Vojmån = Hydropower with Nival flow regime (spring peak)	Tiétar = 150 km; Vojmån = 225 km;	life-form, Mediterranean, Boreal, flow alteration, vegetation encroachment
Bejarano and Sordo-Ward (2011) evaluated the patterns of tree and shrub distribution on a boreal and a Mediterranean river post damming and related these to flow alteration. The Vojman River in Sweden experienced no difference in mean annual flow though flow fluctuations decreased, while the mean annual flow decreased by 37% on the Tietar River in Spain while flow fluctuations remained but decreased in magnitude. Patterns of woody vegetation establishment changed along both rivers, with both trees and shrubs moving closer to river's edge and down in elevation above water level. However, trees moved closer along the Vojman while shrubs moved closer on the Tietar. This is likely due to the periodic flooding that still occurs along the Tietar, frequently disturbing the floodplains and creating an environment more conducive to shrub than tree growth. Along with this, vegetation along the Tietar established on bare channel margins, bars, and islands followed by vertical accretion and lateral expansion as the main channel became more narrow. Vegetation along the Vojman expanded mainly along channel margins that were previously emerged. The authors concluded that shrub expansion is preferred downstream of dams that are on lower energy streams with a sandy substrate in a more unpredictable environment with maintained periodic floods. Therefore, it is important to understand that vegetation in different regions will respond differently to flow regulation and is also influenced by climate, geomorphology and vegetation characteristics.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Bejarano, M.D., C. Nilsson, M.G. Del Tanago, and M. Marchamalo. 2011. Responses of riparian trees and shrubs to flow regulation along a boreal stream in northern Sweden. Freshwater Biology (56): 853-866.	2011	Dam Effects on Vegetation	Peer Reviewed Basic Research	Northern Sweden	Boreal	3543.3 sq km	Dammed	225 km	dam, degree of regulation, ecological responses, flow regulation, northern Sweden, riparian vegetation, river, shrubs, trees
Bejarano et al. (2011) aimed to quantify the ecological impact of flow regulation on riparian trees and shrubs pre- and post-dam operation along a gradient of distances downstream of a dam on the Vojm River in Sweden. In particular, how the degree of regulation affects trees and shrubs. The Volm experiences reduced flow fluctuation, seasonal flow peaks opposite those that naturally occur (peak in winter versus summer), and overall reduced magnitude of floods. Resultantly, coarser substrata were found upstream versus down and a variety of changes in woody species establishment patterns, composition, and richness occurred. All woody vegetation advanced closer to the main channel (trees on average 3.8 m closer and shrubs 1.0 m) and were shorter (0.4 m for trees and 0.2 m for shrubs) post-dam. The post-dam extent of riparian vegetation decreased from pre-dam cover by 62% immediately downstream of the dam and 31% at the sites furthest from the dam, and the floristic similarity of pre- and post-dam tree species was significantly higher downstream than upstream. DCA ordination showed flow regulation to be most important in determination of tree species composition, while for shrubs local conditions such as substratum, bank topography, and water turbulence were more important in determining composition. Overall, these results showed the degree of regulation to be less further downstream from the dam, decreasing from 49% at the most upstream sites to 30% 65 km downstream. The authors attributed this partially to the "healing effect" of tributaries that enter the Vojm and contribute water and sediment to augment hydrogeomorphological and vegetative recovery, especially of trees.									
Bejarano, M.D., M.G. del Tango, D.G. de Jalon, M. Marchamalo, A. Sordo-Ward, and J. Solano-Guitierrez. 2012. Responses of riparian guilds to flow alterations in a Mediterranean stream. Journal of Vegetation Science 23: 443-458.	2012	Riparian Response to Flow Alteration	Peer Reviewed Basis Research	Tietar River, Central-Western Spain	Mediterranean	4478 sq km	Agricultural Dam	150 km	Composition; Diversity; Establishment patterns; Mature forest; Pioneers; Shrubland; Stream water declines
Bejarano et al. (2012) investigated riparian response to stream water declines, and observed the most resilient and sensitive stand-type to the stream water declines (decrease of ~40%). The analysis showed a response to four environmental gradients, flood inundations, moisture, canopy, and grain size; and species characteristics related to stem strength, rooting depth, drought- and flood-tolerance, etc. and then contributed success to the new environmental conditions. The stream water decline led to a barren substrate that allowed establishment of species who could survive the new flow regime, drought, and large drag forces from flooding. The new shrubland had lower species diversity than the pre-dam shrubland, however the encroachment of the upland species on the pre-dam shrubland left for higher diversity in that band. The native late-successional tree-species were not able to colonize the post-dam shrubland due to high water (drag forces and anoxia) and consistent water demands (drought intolerance). The response was a severe decline in mature forest, and anticipated irreversible impacts.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Beltaos, Spyros and Brian C. Burrell. 2002. Extreme ice jam floods along the Saint John River, New Brunswick, Canada. The extremes of the Extremes: Extraordinary Floods (Proceedings of a symposium held at Reykjavik, Iceland, July 2000), no. 271.	2002	Ice Jams and flood stage	Peer Reviewed Basic Research	Saint John River Basin - Maine (USA), SE Quebec, and western New Brunswick (Canada)	Boreal	55, 100 km^2	hydroelectric	700 km	breakup, extreme event, flood, frequency, global warming, ice jam, return period, river, water level
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Beltaos and Burrell (2002) investigate floods caused by ice jams on the Saint John River in New Brunswick, Canada. The most extreme floods on the Saint John River were caused by spring break-up of ice jams. The study briefly evaluates ice jam processes and flooding potential by large aggregate thickness and roughness of the ice jam. The region’s historical hydroclimatic records are analyzed to identify evidence of future extreme flooding by factors that control ice jamming. Evidence suggests more frequent mid-winter jams and higher April flows that have the potential to increase ice jamming.									
Bendix, J. and J.C. Stella. 2013. Riparian vegetation and the fluvial environment: a biogeographic perspective. In J. Shroder Jr., D. Butler, and C. Hupp, editors. Treatise on Geomorphology 12. Academic Press, San Diego, CA.	2013	Fluvial processes and riparian vegetation	Literature Review	International	All				None
Bendix and Stella (2013) set out to review existing literature on the interactions between riparian vegetation and fluvial dynamics and to show that it is impossible to understand either of these without a biogeomorphic approach. They began by discussing the evolution of research on riparian ecology and fluvial processes from the beginning of research on the topic and gave specific examples of research in particular areas of interest. They used relevant literature to present six specific mechanisms of hydrogeomorphic impact on riparian vegetation including: flood energy, sedimentation, prolonged inundation, water table depth and dynamics, soil chemistry, and propagule dispersal. They turned the tables to present some of the influences vegetation can have on geomorphology such as: stream velocity, large woody debris initiation and evolution of landforms, bank cohesion, and channel form. Lastly, they discussed the complexity of feedbacks and indirect effects of geomorphology and riparian vegetation. The authors then reviewed published literature and broke apart studies into categories such as biome, scale, and process studied. They found that most published studies focused on the impacts of flood energy and water table distance on riparian vegetation in North America, Europe, and Australia, in temperate areas, and at large scales.									

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<tr><td>Bergeron, Normand E., André G. Roy, Diane Chaumont, Yves Mailhot, and Éric Guay. 1998. Winter geomorphological processes in the Sainte-Anne River (Québec) and their impact on the migratory behavior of Atlantic tomcod (Microgadus tomcod). Regulated rivers: Research & Management 14: 95-105.</td><td>1998</td><td>Effect channel morphology on migratory fish</td><td>Peer reviewed Basic Research</td><td>Sainte-Anne River, Quebec</td><td>Boreal</td><td></td><td>free-flowing</td><td></td><td>Atlantic tomcod, fish migration, channel morphology, flow velocity, tidal cycle</td></tr>
<tr><td colspan="10">While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Bergeron et al. (1998) study the effect of channel cross-sectional area and flow properties on the winter migration of Atlantic tomcod in the Sainte-Anne River, Québec. Channel morphology and flow conditions at the mouth of Sainte-Anne River that enable the migration of Atlantic tomcod are observed to be driven by ice cover and tidal regime. Through surveyed transects of morphology and underwater video observations, tomcod migration was observed. Ice cover and sand bars were found to limit cross-sectional area resulting in an increase flow velocity that limited upstream migration of tomcod. Rising tide however, resulted in an upwelling moving upstream, and was found to be preferential for migration up into the Sainte-Anne River.</td></tr>
<tr><td>Best, Heather, James P. McNamara, and Lee Liberty. 2005. Association of Ice and River Channel Morphology Determined Using Ground-penetrating Radar in the Kuparuk River, Alaska. Arctic, Antarctic, and Alpine Research 37: 157-162.</td><td>2005</td><td>Ice effect on channel morphology</td><td>Peer reviewed Basic Research</td><td>Kuparuk, Alaska</td><td>Boreal</td><td>8140 km^2</td><td>free-flowing</td><td></td><td>None</td></tr>
<tr><td colspan="10">While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Best, McNamara, and Liberty present a conceptual model that identifies a downstream transition from bedfast ice to floating ice as the agent of step change in channel size due to enhanced bank erosion. Bedfast ice and floating ice were mapped using ground-penetrating radar (GPR) on the Kuparuk River, Alaska. Ice thickness estimations were developed from GPR data and degree-day modeling. The study proposes that channels upstream of the step change are formed from summer fluvial processes and the channels increase in size by a power function moving downstream until the proper depth to develop floating ice is reached at the step change. It is unknown if the shift in channel size is due to increased ice-induced bank erosion or the lack of bed protection due to bedfast ice. The favoring of channel widening over channel deepening downstream of the step change however, provides evidence that suggests observed shifts in channel size are due to increased bank erosion due to ice.</td></tr>
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Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Blackburn, J. and F. Hicks. 2003. Suitability of Dynamic Modeling for Flood Forecasting during Ice Jam Release Surge Events. Journal of Cold Regions Engineering 17, no. 1: 18-36.	2003	Ice Jam Surge Modeling	Peer reviewed Basic Research	Saint John River, New Brunswick	Boreal		run-of-river hydroelectric	100 km reach	ice jams; Surge; Flood forecasting; Dynamic models.
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Blackburn and Hicks (2003) evaluate the suitability of dynamic hydraulic flow modeling techniques to adequately model ice-induced flood events. The study was initiated after an ice-jam induced flood event on the Saint John River in 1993 caused such high water levels further upstream that the Trans-Canada Highway was temporarily closed. The CDG finite element method was selected as the hydraulic flood routing model due to its success in adequately modeling other dynamic events. Saint Venant equations were used to model natural channel geometry and nonuniform velocity distributions. The model successfully produced observed peak stage and surge propagation speed. The study found channel geometry that was more representative of existing conditions to be a significant factor to suitably model ice jam release surge events.									
Boucher, E., Y. Begin, and D. Arseneault. 2009. Impacts of recurring ice jams on channel geomorphology in a small high-boreal watershed. Geomorphology 108: 273-281.	2009	Ice Jam Effects	Peer Reviewed Basis Research	Necopastic River, Quebec, Canada	Boreal	250 sq km	Free Flowing		ice jams, fluvial geomorphology, hydraulic geometry, dendrogeomorphology, ice scars, high boreal
Boucher et al. (2009) suggest that channels affected by ice erosion appear enlarged, and induce an important retreat of the upper bank. If ice jams occur with a frequency of less than every five years, the enlarged channel presents a two-level, ice-scoured morphology; greater than a five year return-interval, the channel doesn't present these characteristics. Study design included dendrochronology of ice jams, cross-sectional analysis, aerial photography, and geomorphological description. From this data, relationships of channel geometry and geomorphic properties to variations in ice-scouring events were garnered. Hydraulic geometry (width and cross-sectional area) was observed to differ in reaches that had a presence of ice-scour. In an attempt to reduce confounding variables, the watershed was determined to be hydroclimatically homogeneous, the watershed possessed homogeneous geologic substrate, and slope was the same for all reaches. The geomorphological function follows a pattern of 1) ice laterally eroding the bank, 2) alluvial deposits in the lower part of the river, and 3) sediments reworked into a flat bench by ice-free floods.									

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<tr><th>Citation</th><th>Year</th><th>Topic</th><th>Source Type</th><th>Location</th><th>Habitat Type</th><th>Watershed Size</th><th>Hydrologic Regime</th><th>River Length</th><th>Key words</th></tr>
<tr><td>Boucher, Étienne, Yves Bégin, and Dominique Arseneault. 2009. Impacts of recurring ice jams on channel geometry and geomorphology in a small high-boreal watershed. Geomorphology 108, no. 3-4: 273-281.</td><td>2009</td><td>Impacts of ice jams on channel geometry and geomorphology</td><td>Peer reviewed Basic Research</td><td>Necopastic River, Quebec</td><td>Boreal</td><td>250 km^2</td><td>free flowing</td><td></td><td>ice jams, fluvial geomorphology, hydraulic geometry, dendrogeomorphology, ice scars, high boreal</td></tr>
<tr><td colspan="10">While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Étienne et al. (2009) investigated downstream variations in channel geometry (i.e., channel width, cross-sectional area, and depth) and geomorphological characteristics on the Necopastic River in northern Québec. The river, located in a small high-boreal watershed experiences frequent spring ice jams. Tree-ring chronologies of ice jams, cross-sectional analysis, aerial photographs, and geomorphological descriptions were analyzed to determine if variations in the frequency of ice-scouring events affects geometric and geomorphological properties. While the sampling strategy was designed to minimize the effects of other environmental processes (i.e., slope, lithology, and climate), it was inconclusive whether observed channel enlargement was caused by ice jams or aforementioned processes. Results demonstrate that hydraulic geometry relations lead to imprecise geometric measurements in the Necopastic River however the data only partly supports the hypothesis by Smith (1979) suggesting ice jams as important and generalized erosive events in ice-affected rivers. The study suggests that some ice jam frequency-of-occurrence thresholds must occur in order to be geomorphologically significant. Geomorphic impacts on the Necopastic River included a “two-level” channel that occurred in frequently ice-scoured sites.</td></tr>
<tr><td>Braatne, J.H., R. Jamieson, K.M. Gill, and S.B. Rood. 2007. Instream flows and the decline of riparian cottonwoods along the Yakima River, Washington, USA. River Research and Applications 23: 247-267.</td><td>2007</td><td>Cottonwood Forest Health Related to Hydro-regulation</td><td>Peer Reviewed Basic Research</td><td>Yakima River, Washington, USA</td><td>Semi-Arid</td><td>15,900 sq km</td><td>Agricultural Dam</td><td>344 km</td><td>age-structure; black cottonwood; Populus trichocarpa; recruitment box model; regulated flows; seedlings; sex-ratios</td></tr>
<tr><td colspan="10">Braatne et al. (2007) studied the flow-regulated Yakima River, and used a combination of vegetation inventory through belt-transects, dendrochronology, and hydrologic analyses to generate a quantitative model to relate colonization to (1) floods and disturbance for germination sites, (2) establishment, and (3) survival. The model demonstrated (1) a lack of correlation between peak flows and cottonwood recruitment following flow regulation, (2) the relative abundance of 40-50 year old cohorts (post regulation) related to gravel mining, (3) little recruitment in the last 20 years, and (4) no recruitment following recent flood events. The model developed a four-step qualitative model for successful cottonwood establishment: (1) hydrologic (or gravel mining) disturbance, (2) moderate flow for germination, (3) gradual flow recession for establishment and late summer survival, and (4) moderate subsequent flows to avoid scouring the established seedlings. Within flow regulated reaches it was found that there was habitat partitioning between cottonwood sexes resulting in an up to 7:1 ratio between males and females, which was posited to be due to females’ need for resource-rich environments and males’ capacity to persist in resource-poor environments.</td></tr>
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Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Braatne, J.H., S.B. Rood, and P.E. Heilman. 1996. Life History, Ecology and Conservation of Riparian Cottonwoods in North America. Pages 57-85 in R.F. Stettler, H.D. Bradshaw Jr., P.E. Heilman and T.M. Hinckley, editors. Biology of Populus. NRC Research Press, Ottawa, Canada.	1996	General cottonwood ecology	Book Section	North America					cottonwood, riparian, life history, riparian revegetation
Braatne et al. (1996) provided a relatively basic descriptive overview of cottonwood ecology. They began with an introduction to the relationship between riparian cottonwoods and alluvial floodplain ecosystems. Then details on life history and ecological properties were provided, such as: sexual reproduction and establishment, asexual reproduction, and growth and maturation. In general, male catkins appear before female and both appear before leaf initiation, seed formation and dispersal occur 3-6 weeks following fertilization, and millions of seeds per tree are released. Seed release coincides with a decrease in peak river flooding and seed germination is rapid though seed viability is short (1-2 weeks). Conditions for recruitment (flooding, deposition, etc.) are not met annually. However when conditions are right, seedlings grow rapidly, with energy preferentially allocated to roots. Trees reach reproductive maturity in 5-10 years and can live to be 100-200 years old. The authors described ten causes of decline in riparian cottonwood populations, focusing on damming and dewatering. They mention it is mainly the wrong patterns of downstream flow regulation that negatively affect these trees. Finally they discussed conservation and restoration strategies and provided lengthy technical notes on how to go about riparian rehabilitation and revegetation.									
Braatne, J.H., S.B. Rood, L.A. Goater, and C.L. Blair. 2008. Analyzing the impacts of dams on riparian ecosystems: a review of research strategies and their relevance to the Snake River through Hells Canyon. Environmental Management 41: 267-281.	2008	Research strategies on dam effects	Literature Review	North America and Snake River			Dammed		Environmental impact analysis, Riparian ecology, River damming
Braatne et al. (2008) review research strategies that have been used to analyze the downstream impacts of dams on riparian ecosystems. With each research strategy, they discuss whether it would be valid to use to investigate the Hells Canyon Complex (HCC) dam effects on the Snake River. Strategies used are broken down into comparative, manipulative, or process based biophysical modeling approaches. Spatial comparative strategies include upstream versus downstream, progressive downstream, and dammed versus free-flowing river comparisons. The authors discuss the difficulties of each approach, such as natural variations in different areas of each river or between rivers. Temporal comparative strategies include pre- versus post-dam and sequential post-dam comparisons. These strategies can also be flawed in that they assume ecological consistency over time in a dynamic environment. The last two strategies are: 1) manipulative (as in flow modification), and 2) process based biophysical modeling of potential dam effects based on an understanding of river hydrology, geomorphology, and riparian plant life history traits. They then presented a variety of confounding factors to analysis of dam effects such as natural variation, coincidental influences, cumulative and sequential impacts, threshold effects, latent effects, and multiple comparisons. An analysis of the HCC and Snake River lead the authors to conclude that a mix of pre- vs. post-damming, dammed vs. free-flowing, and upstream vs. downstream comparisons along with process-based modeling would be the best strategy to investigate HCC effects. They suggest that strategies are combined for the most effective analysis.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Brand, L.A., J.C. Stromberg, D.C. Goodrich, M.D. Dixon, K. Lansey, D. Kang, D.S. Brookshire, and D.J. Cerasale. 2011. Projecting avian response to linked changes in groundwater and riparian floodplain vegetation along a dryland river: a scenario analysis. Ecohydrology 4: 130-142. doi: 10.1002/eco.143	2011	Dam Effects on Vegetation and Birds	Peer Reviewed Basic Research	Southwestern United States, San Pedro River	semi-arid		Free flowing		avian abundance; *Populus*; ecohydrology; dryland river; groundwater; riparian; *Tamarix* ; scenario modeling; space-for-time substitution
Brand et al. (2011) modeled nine different scenarios of groundwater change (pumping or recharge) on the unregulated San Pedro River in the southwestern United States and the effects these changes would have on vegetation structure and bird abundance. They found that under mild to extreme groundwater drawdown, cottonwood/willow forests would decrease from a current percent cover of 58% to 46-10% depending on extremity. Along with this, abundance of canopy nesting bird guilds would decrease by 48-17%. Oppositely, cover of saltcedar would increase from the current 21% cover to 34-73% with mild to extreme drawdown, and allow for a 19-31% increase in midstory nesting bird guilds. Other bird guilds including: understory nesting, water-obligate, and spring migrants would all decrease, with water-obligate species experiencing the greatest declines. With groundwater recharge scenarios, these effects appeared to reverse but little change occurred with mild recharge. These results show the importance of adequate groundwater to maintain high proportions of cottonwood/willow forests and permit continued high abundance of several different bird guilds. Additionally, canopy nesting bird abundance could be used as an indicator of riparian condition along rivers in the southwestern United States.									
Brandt, S.A. 2000. Classification of geomorphological effects downstream of dams. Catena 40: 375-401.	2000	Geomorphic Effects of Dams	Peer Reviewed Basis Research						Fluvial erosion; Sediment deposition; Alluvial; Reservoirs
Brandt (2000) review the downstream effects of dams and devise a typology consisting of nine cases using Lane's balance between discharge, sediment load, grain size, and river slope. The model typology is then used to estimate possible resulting cross-sectional geomorphology through changes in released flow and sediment load relative to transport capacity. The typology relates a change in discharge (increase, decrease, or no change) to the relationship of sediment load to capacity (greater than, less than, or equal to) to determine stream geomorphological alterations – this totals nine classes. The nice classes are described, and then descriptions of changes over time and distance from the dam are discussed concerning width and bed-level changes. No discussion of riparian process is present.									
Brittain, J.E. and A.M. Milner. 2001. Ecology of glacial fed rivers: current status and concepts. Freshwater Biology 46: 1571-1578.	2001	Ecology of Glacial Streams	Peer Reviewed Basis Research	Europe North of the French Pyrenees					alpine, arctic, glacier-fed rivers, hydrological change, macroinvertebrates, model
Brittain and Milner (2001) is an introductory article to a special issue of Freshwater Biology on the aspects of glacial-fed river ecology. The unique characters of arctic and alpine areas are typically related to varying hydrological regimes in the summer, which affect suspended sediment, turbidity, hydraulic stress, and bedload transport. Winter months exhibit fewer differences, with most streams being dominated by groundwater inputs. These regions are typified by sharp gradients in environmental conditions resulting in drastic changes in riparian vegetation and instream conditions such as temperature. The historical study of these systems demonstrated the loss of glacial-fed streams, and a shift from glacial-fed to snowmelt driven systems. Glacial-fed systems typically have higher predictability in species composition due to the harsh environmental conditions. The objective of this special issue is to identify primary physical and chemical variables to determine the distribution of macroinvertebrates in glacially influenced catchments to test the Milner and Petts (2004) conceptual model of glacial-fed systems.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Bruno, M.C. and A. Siviglia. 2012. Assessing impacts of dam operations--interdisciplinary approaches for sustainable regulated river management. River Research and Applications 28: 675-677.	2012	Special Issue Introduction	Introduction Article						environmental flow; hydropeaking; hydropower; dam; compensation flow
Bruno and Siviglia (2012) is an introduction to a special issue of the European Geosciences Union General Assembly. The goal of the session was to promote interdisciplinary hydroecological research to improve the understanding of dam operation consequences and to stimulate and increase scientific exchanges between different groups of scientists. Nine papers included in the special issue are introduced: two dealing with the impact of increased or reduced flow variability on below dam biota, 4 dealing with the range of approaches to set environmental flows of dams, and finally 3 dealing with different aspects of dam mitigation.									
Burke, Michael, Klaus Jorde, and John M. Buffington. 2009. Application of a hierarchical framework for assessing environmental impacts of dam operation: changes in streamflow, bed mobility and recruitment of riparian trees in a western North American river. Journal of environmental management 90: S224-36.	2009	Environmental Impacts of Dam Operation		Kootenai River basin (British Columbia, Montana and Idaho)	temperate	41,910 km^2	flood control/hydroelectric		Reservoir operations, Ecosystem impacts, Operational losses, Hierarchy of impacts, Hydrologic alteration, Instream flow, Riparian recruitment
Burke, Jorde and Buffington (2009) develop a framework for assessing environmental impacts of dams through analysis of three study effects. The study area located on the Kootenai River, is a 233 km reach located between two dams. Study effects include 1) first-order impacts in hydrology, 2) second-order impacts quantifying changes in channel hydraulics and bed mobility, and 3) third-order impacts on recruitment of riparian trees. The study analyzed each effect through stream gages, 1D flow model and recruitment box analysis, respectively. The Libby Dam was found to primarily control the first- and second-order impacts. Both dams however, were found to diminish riparian vegetation recruitment. The framework presented is a tool to isolate specific operational scenarios when more than one regulation system is in place. Further, once a framework is established, predictions can be identified that aid in future river management.									
Calay, R.K., V.K. Sarda, and R. Dhiman. 2008. An empirical approach to river bed degradation. International Journal of Multiphysics 2, no. 4: 407-419.	2008	River Bed Degradation due to Regulation	Peer reviewed Basic Research						River bed degradation, empirical model, alluvial channel
Calay, Sarda and Dhiman (2008) discuss various approaches to quantifying river bed degradation due to regulation. First, their study evaluates theoretical considerations of the degradation phenomenon including variables such as channel geometry and irregularities, type of bed and bank material and slope. Experimental degradation data was derived from physical modeling results presented in Newton (1951) and Bhamidipaty and Shen (1969). From this data, an empirical method that uses known hydrologic and hydraulic variables was developed to predict bed profiles in a degrading stream due to elimination of sediment input. The estimates of bed degradation from the empirical method were found to be satisfactory.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Callaway, R.M. and L.R. Walker. 1997. Competition and facilitation: a synthetic approach to interactions in plant communities. Ecology 78(7): 1958-1965.	1997	Plant Community Competition and Facilitation	Literature review						community; competition; facilitation; indirect interactions; interactions; life stage; plant community; positive interactions.
Callaway and Walker (1997) reviewed and synthesized literature on the balance of competition and facilitation in plant communities. The authors discussed the history of experiments on this topic and gave specific examples of studies concentrating on the co-occurrence of positive and negative effects. They presented factors that have been considered in determining the balance between positive and negative effects. The four main factors they presented were life stage (size, density, etc.), physiology (as related to moisture and light), indirect interactions (a third species modifying the interaction between two other species), and abiotic environmental stresses. Within each category they discussed relevant studies, with a focus on a study by Walker and Chapin (1987) in central AK and Glacier Bay, AK that showed variations in facilitation and competition between *Alnus* spp. and other shrub and tree species depending upon one of these four factors. Finally, they presented a conceptual model based upon a hypothesis confirmed in many studies that facilitation appears to increase in intensity with benefactor (nurse plant) size and in abiotically stressful environments.									
Charron, I., O. LaLonde, A.G. Roy, C. Boyer, and S. Turgeon. 2008. Changes in riparian habitats along five major tributaries of the Saint Lawrence River, Quebec, Canada: 1964-1997. River Research and Applications 24: 617-631.	2008	Riparian Landscape Change	Peer Reviewed Basic Research	St. Lawrence River tributaries, Quebec, Canada	Temperate		3 regulated and 2 unregulated		riparian landscape; temporal change; GIS; aerial photograph; Saint Lawrence
Charron et al. (2008) quantified the spatiotemporal change in the landscape around five major tributaries to the Saint Lawrence river in Quebec and related them to either natural or anthropogenic changes. On average 25% of riparian land changed from one cover type to another. Natural changes were more important than anthropogenic changes on two rivers and changes were relatively equal in importance on the other three rivers. Natural change ranged from 10-30% of riparian land area. The most important natural change was change in cover from water to riparian vegetation and vice versa, showing that river migration, erosion, and depositional processes are occurring, especially on more natural rivers. Anthropogenic change was less at 6-17%, and this is likely because most human impacts on these riparian areas occurred prior to the study period (1964-1997). However, patches of riparian vegetation became more numerous, less irregularly shaped, and more isolated from each other during this time period. Notably, rivers respond to stresses differently and more natural rivers continue to have more natural changes along their riparian zones than those with heavier human influences. More settled rivers appear to have more permanent landscape cover and are less sensitive to environmental change.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Church, M. 1995. Geomorphic response to river flow regulation: case studies and time-scales. Regulated Rivers: Research & Management 11: 3-22.	1995	Flow regulation effects on channel morphology	Peer Reviewed Basic Research	Peace River and Kemano River, British Columbia	Boreal		Regulated	1250 km and 16 km reach	channel adjustment; flow regulation; gravel beds; riparian zones; river morphology; sand beds; sediment transport; time-scales
Church (1995) modeled and evaluated the effect of flow regulation without sediment interruption on two rivers in British Columbia. Sediment is usually captured by dams and has major effects on channel morphology and riparian vegetation, but rarely are the effects of flow regulation evaluated independently. The Peace River is regulated to maintain its natural mean flow, but decrease peak flows and models estimated it would become about 60% of its original width and 75% of its original depth, and decrease its velocity to 90% of the original. This would prohibit this river from moving cobble and gravel and thus create alluvial fans at the mouths of tributaries leading to a stepped river profile between tributaries, in time. On the other hand, the Kemano River was regulated to maintain peak flows and increase mean flows, which is uncommon in flow regulation. Models of the Kemano estimated the river width and depth would increase to 102% and 107% of the original, respectively. However, observed changes did not follow those modeled and the Kemano actually increased in size for the first 21 years of flow regulation and then decreased greatly and experienced channel degradation. This study shows the importance of using adequate time scales in modeling morphological channel adjustments and the need to incorporate sediment transfer within the river into the model. It is important to understand that channel adjustments to flow regulation can take up to several millennia.									
Church, Michael and Jiongxin Xu. Post-regulation Morphological Change on Peace River. In The regulation of Peace River. ms. Edited by Michael Church. In preparation.	In preparation	Dam effect on morphology	Chapter in Book	Peace River in British Columbia and Alberta	Boreal		hydroelectric	1250 km	post-dam, vegetation establishment, channel narrowing
Church and Xu (In preparation) evaluated the Peace River's morphological response to regulation through field observations combined with mapping and comparisons of epoch aerial photographs. The study area includes the five reaches below the second dam (763 km) which comprises approximately two thirds of the river below both dams. The study found the morphological response in the upper, cobble-gravel reach to primarily be passive (i.e., reduced main channel flows are not competent to mobilize the bed material so vegetation establishment on channel bars and sand deposition below a tributary confluence are the primary factors in channel change). Below other tributary confluences, aggradation is occurring. In a confined reach, channel change was minimal. In a multi-channel reach, back-channel abandonment was observed. Below the Smoky River confluence, ice jams were found to maintain pre-regulation channel dimensions. A reduction in slope and confinement downstream of Carcajou in conjunction with a transition to a sand-bed channel explains the aggradation below the gravel-sand transition and channel narrowing during to silt–infill of back channels. In the Peace-Athabasca lowland, morphological response includes an increase in the development of river channel bars. Throughout Peace River, the active channel has narrowed since regulation. Vegetation establishment on river margins and channel bars coupled with back channel filling of silt, are the primary processes driving channel narrowing.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Church, Michael. The hydraulic geometry of Peace River. In The regulation of Peace River. ms. Edited by Michael Church. In preparation.	In preparation	Dam effect on downstream hydraulic geometry	Chapter in Book	Peace River in British Columbia and Alberta	Boreal		hydroelectric	1250 km	boreal river, flow regulation, flow resistance, hydraulic geometry, Peace River
Church (in preparation) performed an analysis of stream gaging throughout the regulated Peace River in order to evaluate changes in hydraulic geometry. There are gages throughout the 6 alluvial reaches that comprise Peace River. For this analysis 29 to 430 gages were used (255 gages were used for ice conditions) over a time period of 7 to 64 years. At two stations, hydraulic geometry is compared between the open-water periods and ice-covered periods. Stations are also compared between pre-regulation and post-regulation. Between gaging stations, hydraulic geometry is constructed by comparing flows of the same frequency. Hydraulic geometries are compiled for each station and discussed. Overall, channels were found to be wider and shallower than expected conditions. Church found this channel adjustment to vary from traditional regime relations for a gravel- and sand-bed river and notes a more passive change occurring on the Peace River. This passive, wider shift in channel geometry could be due to slow vegetation establishment or the effects of ice.									
Clark, J.S., B. Beckage, P. Camill, B. Cleveland, J. HilleRisLambers, J. Lichter, J. McLachlan, J. Mohan, and P. Wyckoff. 1999. Interpreting recruitment limitation in forests. American Journal of Botany 86(1): 1–16.	1999	seedling recruitment	Literature review						dispersal; establishment; fecundity; forest dynamics; mortality; population growth; seed rain.
Clark et al. (1999) review the body of literature including more than 100 studies published between 1985 to 1999 and key cited articles completed prior to 1985 to examine seed rain, seedling growth, seedling establishment, seed banks, and sapling and tree growth and mortality. Key questions include how recruitment is sampled across the body of literature and whether sampling effort is sufficient across the different studies of different temporal and spatial scales to accurately characterize conditions. Clark et al. (1999) used results from a 7 year (1991-1998) monitoring effort on permanent plots in the southern Appalachians (Clark, Macklin, and Wood 1998) to assess how shorter-term sampling efforts affect the ability to estimate vital recruitment rates.									
Collins, B.D., M.R. Montgomery, K.L. Fetherston, and T.B. Abbe. 2012. The floodplain large-wood cycle hypothesis: A mechanism for the physical and biotic structuring of temperate forested alluvial valleys in the North Pacific coastal ecoregion. Geomorphology 139-140: 460-470.	2012	Floodplain large-wood cycle	Literature review	Pacific Northwest: examples from Queets and Nisqually Rivers	Temperate				Wood debris, Riparian forest, Fluvial geomorphology, Foundation species, Biogeomorphology, River restoration
Collins et al. (2012) described the large-wood cycle on rivers of the Pacific Northwest. They describe that large pieces of wood known as "key pieces" initiate and stabilize wood jams by entering rivers. These key pieces create lower localized shear stress, permitting sediment accretion and eventually creation of stable "hard points", or islands. These hard points can resist erosion for centuries and permit refugia for future riparian forests and thus create new large key pieces that enter the large-wood cycle. This cycle provides resilience to the fluvial system of these rivers with the net result being greater biotic diversity and a more complex physical structure. For this reason, the authors described large trees as "foundation species" of these ecosystems. Finally, Collins et al. discussed the nature of this cycle in other areas of the world and how knowledge of the cycle can be used for management and restoration of floodplain ecosystems.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Collins, W.B. and D.J. Helms. 1997. Moose, *Alces alces,* habitat relative to riparian succession in the boreal forest, Susitna River, Alaska. Canadian Field-Naturalist 111(4): 567-574.	1997	Moose Habitat and Floodplain Succession	Peer Reviewed Basic Research	Susitna	Boreal	50,764 sq km	Free-flowing	504 km	Moose, *Alces alces*, vegetation succession, disturbance, floodplain, browsing, riparian, Susitna River, Alaska.
Collins and Helm (1997) investigated the productivity and consumption of moose browse along floodplain and boreal forest of the Susitna River, AK. They determined that feltleaf willow (*Salix alaxensis*) is the primary moose browse, and Early Shrub plant communities contained the most of this browse species and were also first in terms of browse consumption by moose. Whereas, Young Poplar Forests were least productive in terms of moose browse. The authors discussed the succession of forests and related productivity of moose browse species from Early Shrub to Alder to Young Poplar Forests to Old Poplar Forests and finally into the oldest plant communities of Birch-spruce forests. They noted that there is rare, localized use of the lower Susitna River floodplain by moose in summer, but that in winter moose appear to be using the floodplain at near capacity. Finally, they state that conditions for vegetation succession and browse production are met by flooding and sediment deposition along floodplains, but that would be disrupted by installment of a hydroelectric dam.									
Cooper, D.J. and D.C. Andersen. 2012. Novel plant communities limit the effect of a managed flood to restore riparian forests along a large regulated river. River Research and Applications 28: 204-215.	2012	Seedling Recruitment and Survival	Peer Reviewed Basic Research	Green River, CO	semiarid		Dammed	16km stretch	cottonwood; demography; environmental flows; fluvial landforms; managed flood; Populus; regulated river; riparian vegetation
Cooper and Anderson (2012) performed a long term experiment along the dammed Green River, CO to determine if a controlled flood similar to pre-regulation floods could lead to recruitment of an ecologically significant number of native trees similar to pre-regulated recruitment. The authors used two methods of disturbance: plowing and herbicide to remove herbaceous vegetation during a controlled flood in 1999 to test this hypothesis. For several years after the flood they evaluated the survival of cottonwood seedlings and found that establishment depended upon presence of bare sediment and also the seed rain received at each plot. They determined that for the Green River, years of flow regulation have caused a shift in ecological state that resists change back to a pre-dam state regardless of flood manipulation to resemble pre-dam flooding. This could be due to managed flows preventing lateral channel migration or not producing enough shear stress, the dense herbaceous vegetation that now covers all areas with seasonally high water tables, or that transported sediment is not enough to bury point bar vegetation and open up these areas for colonization. The authors determined that repeated floods and mechanisms to improve survivorship of cottonwoods need to occur if existing cottonwood forests in this area are to be even partially replaced.									

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<tr><td>Cooper, D.J., D.C. Andersen, and R.A. Chimner. 2003. Multiple pathways for woody plant establishment on floodplains at local to regional scales. Journal of Ecology 91: 182-196.</td><td>2003</td><td>Plant Establishment</td><td>Peer Reviewed Basis Research</td><td>Yampa and Green River, Colorado, USA</td><td>Arid</td><td></td><td>Free Flowing and Regulated, respectively</td><td>174 km</td><td>Colorado, dams, floods, Green River, Populus, regulated river, riparian, Tamarix, tree ageing, unregulated river, Utah, Yampa River.</td></tr>
<tr><td colspan="10">Cooper et al. (2003) use dendrochronological analysis to study alluvial and canyon reaches of rivers and to determine events necessary for recruitment. Recruitment occurred on (1) vertically accreting bars in the unregulated alluvial valleys, (2) high alluvial floodplain surfaces following large flood events, (3) vertically accreting margins in canyons, (4) vertically accreting intermittent/abandoned channels, (5) low elevation bars and debris fans during drought, and (6) bars and channels formed prior to flow regulation. Logistic regressional analysis demonstrated flow variability and interannual patterns of flow, rather than individual large floods, control most establishment. In unregulated reaches establishment occurred at 100-300 cm above base flow, however following flow regulation recruitment bands occurred on lower surfaces at 75-125 cm. Establishment occurred in silty to loamy sediments.</td></tr>
<tr><td>Cooper, D.J., D.M. Merritt, D.C. Andersen, and R.A. Chimner. 1999. Factors controlling the establishment of Fremont cottonwood seedlings on the upper Green River, USA. Regulated Rivers: Research & Management 15: 419-440.</td><td>1999</td><td>Cottonwood establishment</td><td>Peer Reviewed Basic Research</td><td>Green: 124,578 km^2, Yampa: 19,839 km^2</td><td></td><td></td><td>Hydrologic regime: Green: dammed, Yampa: largely unregulated</td><td>River length: Green: 1,175 km, Yampa: 402 km</td><td>alluvial soil; Colorado; competition; cottonwood; desiccation; Populus; regulated river; riparian vegetation; seedling population dynamics; tamarisk; Tamarix; Utah</td></tr>
<tr><td colspan="10">Cooper et al. (1999) aimed to examine establishment requirements of Fremont cottonwood (Populus deltoids Marshall subsp. wislizenii (Watson) Eckenwalder) seedlings in natural and experimental settings. They found that natural seed rain of Fremont cottonwoods and invasive competitor: tamarisk (Tamarix ramosissima Ledebour) was abundant and did not restrict establishment of either species. Early summer peak stream flows appeared to promote cottonwood establishment while mid to late summer peaks promoted tamarisk. Cottonwood seeding survival was tested under varying water, shade and competition regimes. Seedling survival was not dependent upon maintaining root contact with groundwater but other factors permitted survival, namely soil with a fine textured layer of at least 10-15 cm in the top 40 cm appeared necessary to support germinants through their first summer. Tamarisk only outcompeted cottonwoods when water was limiting. Finally, heavy shading only increased seedling mortality in experimental plots in situations where competition for soil moisture was high such as in unwatered plots, dense cottonwood plots, and plots with adult tamarisks. The authors noted that in this area the primary sites for cottonwood establishment are stream bars above base flow with fine-textured soil layers, and they provided suggestions for how Flaming Gorge Dam outputs can be regulated to provide ideal stream conditions for establishment.</td></tr>
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Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Curran, Janet H., and Monica L. McTeague. 2011. Geomorphology and Bank Erosion of the Matanuska River, Southcentral Alaska. U.S. Geological Survey Scientific Investigations Report 2011 – 5214, 52 p.	2011	Geomorphology and Bank Erosion	White-paper report	Matanuska River, Alaska	Boreal	2,100-mi^2	free-flowing		None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Curran and McTeague (2011) qualitatively and quantitatively assessed bank erosion on the Matanuska River in southcentral Alaska. By mapping the channel and floodplain at various locations between the Matanuska Glacier to the river mouth (for a total study area of 65-miles), erosion was assessed in order to provide erosion hazard data. Bank erosion was quantified by comparing bank lines between 1949 and 2006. Erosion since 1949 was found to be localized and episodic. This is evidenced by the majority of the quantified erosion (64 %) occurring at less than 10 percent of the banks. Erosion was found not to correlate to peak streamflow or mean annual streamflow. Shifts in the channel pattern were found to occur at both annual and decadal intervals. At the Matanuska Glacier, a shift from a braided to more channelized river occurred suggesting changes in the glacier's sediment or flow regime. The study produced shapefiles of bank material and height along the river corridor and distribution of geomorphic features that may present erosion hazards that can be overlain to identify locations of erosion risk. The products are tools for risk assessment and erosion management. On the Matanuska River, high erosion hazards included active tributary fans and active landslides.									
Delaney, Allan J., Steven A. Arcone, and Edward F. Chaocho, Jr. 1990. Winter Short-Pulse Radar Studies on the Tanana River, Alaska. Arctic 43, no. 3: 244-250.	1990	Ice Studies	Peer reviewed Basic Research	Tanana River, Alaska	Boreal		free-flowing		short-pulse radar, airborne surveys, dielectric permittivity, groundwater, alluvial-bedding patterns, ice thickness, Tanana River, Fairbanks, Alaska
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Delaney et al. (1990) tested short-pulse radar's capability to locate open-water channels, measure ice thickness and measure thickness of deep seasonal frost on the Tanana River. The paper also presents a discussion of the effectiveness of airborne radar reflections for surface profiling. Holes were drilled along the winter roadway on the Tanana River to measure ice thickness, water depth, frost depth and depth to the river ice-alluvium contact. Reflection and refraction soundings were performed in order to identify the electrical properties of the riverbed material. The study found airborne radar surveys to measure depth of frost beneath river braid bars and locate unfrozen channels effectively and identified frozen river sand and gravel as a suitable radar propagation medium.									

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<tr><td>Densmore, R. and J. Zasada. 1983. Seed dispersal and dormancy patterns in northern willows: ecological and evolutionary significance. Canadian Journal of Botany 61: 3207-3216.</td><td>1983</td><td>Willow seed dispersal</td><td>Peer Reviewed Basic Research</td><td>Alaska</td><td>Boreal</td><td></td><td></td><td></td><td>None</td></tr>
<tr><td colspan="10">Densmore and Zasada (1983) described the two patterns of reproduction found in northern willow species: summer and fall dispersed seeds. They showed that summer dispersed seeds are non dormant and germinate completely at temperatures ranging from 5-25 degrees C. Fall dispersed seed remained on the plant for longer period of time during which seeds established their dormancy. Once dispersed, seeds required cold stratification of at least one month and then germinated completely at 25 degrees C and showed less complete germination at lower temperatures. This was described as conditional dormancy. The authors showed that all summer dispersed seeds showed the same patterns of germination regardless of collection site or year. However, the date of dispersal of fall seeds resulted in variation in germination time; seeds that remained on the plant longer were less dormant. Finally, the authors discussed the evolution of fall dispersed seeds, and how it has permitted seedlings, especially in tundra regions, to benefit from a longer growing season than summer dispersed seeds.</td></tr>
<tr><td>Douhovnikoff, V., J.R. McBride, and R.S. Dodd. 2005. Salix exigua clonal growth and population dynamics in relation to disturbance regime variation. Ecology 86(2):446-452.</td><td>2005</td><td>Willow seedling recruitment and clonal growth</td><td>Peer Reviewed Basic Research</td><td>Mokelumne River and Cosumnes River, California, USA</td><td>Semi-arid</td><td>1712 sq km and 1388 sq km respectively</td><td>dammed and undammed, respectively</td><td></td><td>clonal growth; colonization; disturbance; genet; molecular marker; ramet; riparian woodland; Salix exigua; willow.</td></tr>
<tr><td colspan="10">Douhovnikoff et al. (2005) utilized DNA fingerprinting to test their hypothesis that clonal growth of Salix exigua is more important for local colonization of riparian communities than seedling recruitment and successive survival. They also wished to determine if a river with less disturbance (the dammed Mokelumne River) would have a greater influence on clones than a river with more disturbance (undammed Cosumnes River). In general clones occupied about 75% of the vegetated area at all sites on both rivers. The percentage of genetically distinct stems averaged around 46%, but the range was greater on the Cosumnes River and inversely related to mean site elevation. All sites were dominated by closely related clones. Clones were larger on the Mokelumne, but there was no significant difference in size between clones and genets on the Cosumnes. On both rivers this data shows that seedling recruitment is not very common, but once a seedling is recruited into the mature willow population it is likely to colonize a large area. This clonal growth permits long term colonization. Reduced disturbance leads to increased clonal growth, decreased seedling recruitment, and a positive feedback cycle wherein larger clones are less likely to be removed by disturbance and eventually leads to sites dominated by large clones with reduced genotypic diversity and site heterogeneity. With time, these large clones are predicted to be replaced by larger and more shade tolerant woody species.</td></tr>
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Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Durand, J.R., R. Lusardi, R. Suddeth, G. Carmona, C.R. Connell, S.E. Gatzke, J. Katz, D. Nover, J.F. Mount, P. Moyle, and J.H. Viers. 2009. Conceptual ecosystem model of sub-Arctic river response to climate change: Kobuk River, Alaska. Report submitted to the Alaska Dept. of Fish and Game, Fairbanks, AK.	2009	Climate Change on Sub-Arctic Rivers	White Paper	Kobuk River, Alaska	Boreal	11000 sq km	Free Flowing	190 km	intermittent pulse flows, climate change, channel change, ice
Durand et al. (2009) examine the geomorphic drivers resulting from climate change in sub-Arctic regions, and make predictions concerning habitat and the biota. The major geomorphic drivers are shown to be a high dependence upon intermittent pulse flows that regulate connectivity between habitat and allow for periods of high off-channel productivity in the late summer, as well as the critical importance of spring break-up in maintaining the habitat complexity and interconnectivity of these systems. From increased scour and erosion, break-up can create 2 to 5 times higher sediment loads than open rivers. Channel complexity and off channel habitat contribute to most of the biological production in the Kobuk River, and maintenance of this connectivity allows for nutrient transport to maintain the flora and fauna. The authors were unable to quantitatively predict the effects of climate change, but qualitatively identified two characteristics that are likely to change and have the most crucial effects: 1) spring break-up conditions, and 2) hillslope changes related to permafrost. Four scenarios were run modifying the two variables – break-up intensity increasing or decreasing, and permafrost changes resulting in either an increased active layer or thermokarsting.									
Elliott, John G. and Lauren A. Hammack. 2000. Entrainment of riparian gravel and cobbles in an alluvial reach of a regulated canyon river. Regulated Rivers: Research & Management 16: 37-50.	2000	Dam effect on sediment entrainment	Peer reviewed Basic Research	Gunnison River, Colorado	temperate		water supply/hydroelectric		Black Canyon of the Gunnison River, critical shear stress, sediment entrainment
Elliott and Hammack (2000) analyzed sediment entrainment potential of a regulated alluvial reach in the Black Canyon. The intent was to identify sediment-entraining discharges on a variety of geomorphic surfaces with gravel and small boulders for estimating flows required for near-natural conditions reservoir releases. Eight cross-sections were surveyed and a one-dimensional hydraulic model was constructed and run for a range of discharges. The annual peak discharge of year of study (1995) was found to entrain sediment on vegetated banks and bars including sediment larger than d50. Many larger particles however, were not moved. Critical shear stress and the entrainment discharge on the same geomorphic surface were found to differ along the reach concluding that no specific streamflow can mobilize d50 at every geomorphically similar location.									

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<tr><td>Ettema, R. 2008. Ice effects on sediment transport in rivers. Sedimentation Engineering: 613-648. doi: 10.1061/9780784408148.ch13</td><td>2008</td><td>Ice Processes</td><td>Book chapter</td><td></td><td></td><td></td><td></td><td></td><td>None</td></tr>
<tr><td colspan="10">Ettema (2008) presents details on each part of the river ice cycle, discusses ice impacts on flow, sediment transport, and channel morphology, and describes relevant research pertaining to each. Ice formation depends on channel size, air temperature, and regulation and forms most readily on cold, clear, windy nights. There are three main types of river ice and Ettema describes in detail the formation of each: bankfast ice, skim ice, and frazil ice. Frazil ice is dominant on alluvial rivers with adequate flow to move sediment. Break up processes occur in three main phases: weakening of ice cover, breakup and ice run, and breakup ice jams. While ice cover persists, flow is influenced. Mainly, the river stage is raised, flow can be concentrated in the thalweg or spread out horizontally, stream velocity decreases, secondary currents decrease, bed sediment transport decreases, and as a result the size and shape of the river bed is altered. Ice can transport sediment mainly via anchor ice formation on the river bed and subsequent rafting of ice and attached sediments. Ice cover also affects bed sediment transport, and Ettema discusses this in detail and provides equations for the multitude of parameters that impact sediment transport such as water temperature, sediment discharge and density, gravity acceleration, channel slope, etc. Finally, ice can impact channel morphology through hydraulic impacts such as redistribution of bed sediment, modification of channel shape, effects on depth and size of adjacent channels and at river confluences, and decreased sediment transport beneath free floating ice. River morphology can also be changed through ice impacts on riverbanks like reduced riverbank strength, and mechanical movement and destruction of riverbank material and vegetation.</td></tr>
<tr><td>Ettema, R. 2002. Review of alluvial-channel responses to river ice. Journal of Cold Regions Engineering 16(4): 191-217.</td><td>2002</td><td>Ice Effects</td><td>Peer Reviewed Basis Research</td><td></td><td></td><td></td><td></td><td></td><td>Alluvial channels; Ice formation; Flow resistance; Rivers; Morphology.</td></tr>
<tr><td colspan="10">Ettema (2002) takes an engineering approach to ice-influenced rivers to assess the changes in hydraulics and geomechanics of ice in rivers – there is little mention of the riparian system, but the connections to sediment and flow are useful. The study is largely conceptual, and starts with a discussion of variables, parameters and dependencies that drive channel hydrology; the author then adapts these traits to ice influence. Such ice-influence conclusions fall into categories of hydraulics, channel morphology, riverbanks, and a summary with these effects working in concert and the effects upon the river. The author concludes that major geometric (geomorphic, but considered geometric within the paper due to the authors method of analysis) parameters do not change appreciably, however river ice likely increases irregularities in the channel planform and frequencies with which the channel cross-section and thalweg alignment shift. Ice adds noise to the signal form of an alluvial channel in dynamic equilibrium.</td></tr>
<tr><td>Ettema, Robert and Leonard Zabilansky. 2004. Ice Influences on Channel Stability: Insights from Missouri's Fort Peck Reach. Journal of Hydraulic Engineering 130, no. 4, 279-292</td><td>2004</td><td>Ice Effect on Channel Stability</td><td>Peer reviewed Basic Research</td><td>Missouri River, Montana</td><td>temperate</td><td></td><td>Fort Peck Dam</td><td>305 km</td><td>Ice cover, Channel Stabilization, Missouri River, Alluvial channels, Aquatic habitats</td></tr>
<tr><td colspan="10">While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Ettema and Zabilansky (2004) present their comprehensive study on alluvial-channel stability and changing bathymetry due to the influence of ice. The study involves studying the winter behavior of the Missouri's Fort Peck reach. Through a general and site specific discussion of various ice processes including formation, presence, and breakup as well as the affect these variables can play on channel properties (local cross-section of flow, transverse bed-slope, thalweg alignment, channel-bed elevation, and bank formation and destruction), the authors present a detailed account of how ice can affect river morphology. On the Missouri River this included a hastening of migration of channel bends, local sites of scour and sediment deposition, and thalweg shifting. Based on these findings, bank protection systems are identified that are better suited for rivers that experience ice.</td></tr>
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Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Ettema, Robert and Steven F. Daly. 2004. Sediment Transport Under Ice. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, ERDC/CRREL TR-04-20.	2004	Sediment Transport under Ice	White-paper report						Erosion, Ice, Ice cover, sediment, sediment transport, winter river flow
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Ettema and Daly (2004) present a comprehensive review of sediment transport under ice. The discussion evaluates four ice-related topics: ice-cover influence on flow distribution, sediment transport by ice, sediment transport under ice and ice influences on channel morphology. Because ice plays an important role in sediment transport and channel morphology this analysis helps inform predictions of possible downstream effects of regulation on rivers that experience ice cover. The study concludes that the magnitude of ice-influence depends on the amount of ice formed and the quantity of conveyed water and sediment. The overall quantity of ice is controlled by the cumulative period of degrees below water freezing temperature and the quantity of water (determined by regulation) will determine the quantity of sediment transport. Each of the four themes is evaluated in detail and factors controlling each topic are identified and discussed.									
Ettema, Robert, Marian Muste, and Anton Kruger. 1999. Ice Jams in River Confluences. US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, CRREL Report 99-6.	1999	Ice Studies	White-paper report		temperate				ice jams
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Ettema, Muste and Kruger (1999) evaluate ice-jam formation in and around river confluences through modeling. Two models were built from field observations of ice jams around confluences. One model evaluated the effect of confluence angle on ice-jam formation and the second evaluated ice-jam formation within the Mississippi and Missouri River confluence. The study identified simple and complex ice processes that lead to ice jam formation within river confluences. Complex processes include merging of ice runs, hydrodynamic pressure, and ice congestion at a confluence bar while simple processes include ice blocked by ice cover, arching ice pieces, and ice entering low flow. The paper identifies formulas for estimating maximum rate of ice conveyance through confluences and discussion of the effectiveness of the ice-jam mitigation technique, bendway weirs in series.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Faustini, John M. and Julia A. Jones. 2003. Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. Geomorphology 51: 187-205.	2003	Large Woody Debris and Channel Morphology	Peer reviewed Basic Research	Mack Creek, Oregon	temperate	5.8 km^2	free flowing		Woody debris; Channel stability; Stream cross sections; Longitudinal profile; Sediment
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Faustini and Jones (2003) evaluate the effect of large woody debris (LWD) on channel morphology, channel stability and sediment dynamics in a boulder-rich mountain stream through analysis of cross-sectional surveys, streamflow data, LWD inventory data, and longitudinal profile surveys. LWD was found to create channel steps between 1 to 2.5 meters high and resulted in low-gradient upstream channel segments approximately 1 to 3 channel widths long. In a comparison of reaches with LWD and without after the largest flood on record, the reach without LWD was found to experience scour and coarsening of the bed material while the reach with LWD was found to experience aggradation in locations upstream of LWD. The reach without LWD was observed to experience less morphological change at the channel scale and conveyed sediment more readily than the reach with LWD.									
Fenner, P., W.W. Brady, and D.R. Patton. 1985. Effects of regulated water flows on regeneration of Fremont Cottonwood. Journal of Range Management 38(2): 135-138.	1985	Seedling recruitment	Peer Reviewed Basis Research	Salt River, Arizona	Arid		Dammed	80 km	None
Fenner et al. (1985) examined the relationship between seed dispersal and regulated versus unregulated flows to explain the current lack of seedling survival on the Salt River in Arizona. To do so they use regression analysis to predict the timing and magnitude of flows that would have been without the current dam in place on this river. The dam appeared to reduce the magnitude of the flood peak, delay the peak from late winter or early spring until late spring or early summer, and increase the duration of high flood waters. The seed dispersal period for *Populus fremontii* on this river was determined to be adapted to the no-dam situation where fresh alluvium was exposed in late winter-early spring and then usually undisrupted for the remainder of the summer. The authors concluded that the dramatic changes in river flow patterns were responsible for the change in vegetation and the lack of seedling recruitment on this river.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Fergus, Tharan. 1997. Geomorphological Response of a River Regulated for Hydropower: River Fortun, Norway. Regulated Rivers: Research & Management 13: 449-461.	1997	Geomorphic response of a regulated river	Peer reviewed Basic Research	River Fortun, Norway	continental	508 km^2	hydroelectric	1600 m reach	hydropower regulation, flood frequency, morphology, vegetation encroachment
Fergus (1997) presents a case study of the geomorphological response of a gravel-bed river regulated for hydropower. The area of study is a 1600 meter reach on the River Fortun in south-western Norway. The post regulation discharge has reduced approximately 35% of its pre-regulation value contributing to the reduction in frequency of large magnitude flood events. The sediment supply however, derived from rapid mass movements, tributary flooding, and channel and glacial erosion, is mainly intact since regulation. Forty seven cross-sections within the study reach have been surveyed 3 times since the dam's construction in 1963 (1973, 1989, and 1995). The cross-sections were used to quantify aggradation and degradation within the study reach. The profiles showed a reduction in channel size and corresponding capacity over time. The river both aggraded and degraded with the greatest amount of aggradation in the upper part of the reach and the greatest amount of degradation in the lower part of the reach where extensive lateral erosion occurred. Overall, the studied reach has a net aggradation since profiles were first surveyed (1973). This has corresponded to increased water surface levels in the upper extent of the study reach at lower flows.									
Ferrick, Michael G, Lawrence W. Gatto, and Steven A Grant. 2005. Soil Freeze-Thaw Effects on Bank Erosion and Stability: Connecticut River Field Site, Norwich, Vermont. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, ERDC/CRREL TN-05-7.	2005	Soil Freeze-Thaw Effects on Bank Erosion	White-paper report	Connecticut River, Vermont	temperate				None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. In this technical report, Ferrick, Gatto and Grant (2005) summarize a 3-year study effort on soil freeze-thaw cycling and corresponding ground-ice growth and melt on the Connecticut River, Vermont. Four areas were evaluated in depth: depth and duration of soil-freeze thaw, effects of freeze-thaw on soil strength and erosional processes, timing and depth of slope failures in the study reach, and hypothesis of soil freeze-thaw as a primary factor in slope failure. Results indicate that compass-orientation of the bank affects the average duration of soil freezing, Soil freeze-thaw was found to affect bank soils up to 0.75 meters below the surface, and the base of bank was found have a cobble armor toe and observed to undercut the bank and correspond to unstable bank slopes.									
Fitzhugh, Thomas W., and Richard M. Vogel. 2010. The impact of dams on flood flows in the United States. River Research and Applications, DOI: 10.1002/rra.	2010		Peer reviewed Basic Research	Rivers across continental U.S.	continental	varies	regulated by various methods	varies	dams; hydrologic alteration; environmental flows; floods; flood control; hydrology; ecological
Fitzhugh and Vogel (2010) applied a method for assessing the hydrologic impact of dams on flood flows on regulated rivers in over 78 % of the continental United States. The study was performed by creating regional multivariate regression models of median annual 1-day maximum flow based on watershed characteristics, dam storage and population density. The method applied explicitly accounts for temporal changes due to climatic and land-use variables. The models present a comprehensive evaluation of flood alteration throughout the United States. With R2 values greater than 0.80, the study determined that regional regression analysis is a successful method for evaluating hydrologic-regime changes due to regulation.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Friedman, J.M. and V.J. Lee. 2002. Extreme floods, channel change, and riparian forests along ephemeral streams. Ecological Monographs 72(3): 409-425.	2002	Cottonwood Establishment	Peer Reviewed Basis Research	6 Reaches: Ephemeral Tributaries of South Platte River, Colorado	Arid	110 - 949 sq km	Free Flowing and Regulated	5.0 - 7.6 km	bottomland forest; channel narrowing; Colorado, eastern; cottonwood, plains; disturbance, fluvial; flood; High Plains; succession.
Friedman and Lee (2002) test the hypothesis that cottonwoods establish on surfaces made available during the post-flood channel narrowing process in ephemeral streams. Methodologically they overlay aerial photography spanning 56 years of the reaches of interest and dendrochronologically measured the study sites. Results show cottonwood establishment was related to low flows at the timescale of a year, but to high flows at the timescale of decades. Typical recruitment occurred following a flood and lasted for up to two decades, and the majority of recruitment was in former channel beds or in newly exposed surfaces where the channel had widened; the identification of this can allow for a reconstruction of flood histories. During years of low-flow flood events, cottonwoods encroach on the widened channel, stabilize the bank, and continue to encroach upon the stream, leading to its narrowing. Flooding alone was not the driving force for cottonwood establishment, but rather the flood-related avulsion or channel widening. The result of senescent cottonwood forests was grasslands.									
Friedman, J.M., G.T. Auble, E.D. Andrews, G. Kittel, R.F. Madole, E.R. Griffin, and T.M. Allred. 2006. Traverse and longitudinal variation in woody riparian vegetation along a montane river. Western North American Naturalist 66(1): 78-91.	2006	Riparian vegetation response to floods and geomorphology	Peer Reviewed Basis Research	San Miguel River, Southwestern Colorado	Semi-arid	4000 km^2	Free flowing		*Populus angustifolia*, recurrence interval, inundation, tributary, flood, channel change, gradient analysis.
Friedman et al. (2006) researched how riparian vegetation patterns are influenced by physical gradients (inundation frequency and geomorphology) longitudinally and traversing the San Miguel River in southwestern Colorado. Riparian communities are dominated by *Populus* spp. on this river and represented 73% of the area mapped. Traverse gradients showed that *Salix exigua* was located closest to the river on surfaces experiencing a flood recurrence interval of <2.2 years, above the were *Alnus incana* and *Betula occidentalis* communities with recurrence intervals of 2.2 to 4.6 years, and above that in the driest zones were *Populus angustifolia* communities with intervals of <22 years for young communities and >22 years for older communities. Longitudinally, downstream up to river km 65.2 at least 88% of riparian vegetation was on surfaces inundated less than every 150 years, while upstream this percentage declined to only 4% at km 120.7. *Populus* was found on surfaces with longer recurrence intervals downstream to upstream while *Salix* was consistently found on low recurrence interval surfaces, and *Betula* and *Alnus* were intermediate. This change in required recurrence interval can be explained by the greater amount of rainfall and reduced evaporation upstream, which adjusts for a decrease in flood water availability. Geomorphologically, deposits from valley side processes such as tributary fans, landslide deposits, beaver ponds, and the dam break of 1909 make up a large percentage of the area dominated by riparian vegetation, and the importance of these processes increases upstream. Finally, *Populus* reproduction was shown to be related to channel migration, and this relationship was more important downstream than upstream.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Friedman, J.M., W.R. Osterkamp, and W.M. Lewis Jr. 1996. Channel narrowing and vegetation development following a great plains flood. Ecology 77(7): 2167-2181.	1996	Vegetation establishment and succession	Peer Reviewed Basic Research	Eastern Colorado, Plum Creek	Semi-arid	782 sq km	free flowing	14 km	bottomland vegetation, channel narrowing, Colorado, cottonwood, dendrochronology, disturbance, flood, patch dynamics, succession
Friedman et al. (1996) described the patterns of vegetation along Plum Creek in eastern Colorado for the 26 years following a major flood. Vegetation along this stream was considered to be in disequilibrium and the channel was continuing to narrow to date since the recovery time following this major flood was long, as is common in arid regions or small watersheds. The morphology of this stream consisted of a channel bed with vegetation dating to the present year (1991), stable bars with vegetation from 1987-1990, old stable bars (1973-1986), and terraces (1965-1972, and pre-1965). The species composition of each zone was related to elevation which influenced moisture availability, flood disturbance, seed dispersal by water, and potentially nutrient availability. Species composition was also influenced by litter, vegetation cover, and sediment particle size. The successional process following channel narrowing resulted in some of the observed differences in vegetation composition of different aged surfaces: reduced flooding permitted establishment, increased root and shoot sizes trapped sediment and reduced erosion causing accretion of the surface which then reduced flood disturbance, litter and shade increased while water availability decreased thereby reducing seedling establishment which in turn reduced the presence of all species that weren't rhizomatous perennials. Some zones, such as the 1965-1972 surfaces, were not formed by successional processes however. These areas were subject to vegetation removal during the flood followed immediately by low moisture availability, thus they are the main areas with few trees, low litter, low vegetation, and little species diversity along this stream. These same channel narrowing and disequilibrium vegetation processes would most likely be seen along dammed rivers or rivers affected by climate change.									
Friedman, J.M., W.R. Osterkamp, M.L. Scott, and G.T. Auble. 1998. Downstream effects of dams on channel geometry and bottomland vegetation: Regional patterns in the Great Plains. Wetlands 18(4): 619-633.	1998	Dam effects on channel morphology and vegetation	Literature Review	Great Plains, U.S.	mainly Semi-arid		Dammed		channel geometry, cottonwood, dam, forest, Great Plains, riparian, sediment
Friedman et al. (1998) reviewed and compiled information on downriver channel morphology and riparian vegetation response to damming in the Great Plains of the US. Formerly braided channels mainly narrowed following damming, while all of the formerly meandering channels investigated experienced a reduced rate of channel migration. There were regional trends in regards to meandering braided channel locations with all of the braided channels occurring south of the Nebraska/South Dakota border and meandering channels located north of this border. High flow variability associated weakly with channel width but strongly with the water source of a river. Channel width was also weakly associated with local sediment type and the authors discussed the past and present geological factors that contributed to channel width and geometry. Channel narrowing contributed to the expansion of pioneer riparian forests in the southwestern plains where braided channels were formerly present. However, after the initial burst of riparian forest development a new equilibrium in channel morphology is reached and succession leads to replacement of riparian species by grasses or more shade tolerant trees. Finally, the authors discussed how this change in riparian vegetation and human/climate induced impacts on riparian vegetation have led to declines in wildlife habitat and populations on the Great Plains.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Gatto, L.W. 1993. Riverbank conditions and erosion in winter. Seventh Workshop on the Hydraulics of Ice Covered Rivers. Committee on River Ice Processes and the Environment. Saskatoon, Saskatchewan, 1993.	1993	Winter erosion	White Paper Report						None
Gatto (1993) discussed the different processes contributing to riverbank erosion in winter. The author first presented the geotechnical processes occurring along river banks and gave examples from individual rivers and lakes. He introduced these processes by stating that erosion depends on the mechanical strength of the soil which in turn depends on a variety of soil characteristics and structural properties. First, the freeze-thaw cycle decreases strength in soils from 1.2-7 times, multiple cycles reduce strength even further, and this "freeze-thaw preconditioning" causes surface sediments to be more prone to erosion by other processes. Second, ground ice can form within the soil which can effectively double the volume of frozen soil and result in frost heaves. These heaves dislodge soil particles which can then fall down slope. Finally, with either ground ice sublimation or ground ice thaw, soil can either fall down slope or melted ice can act as a lubricant and cause soil to flow downhill. Next, Gatto mentioned different ice actions, such as spring ice retreat, thrust, or shear along banks that can remove and transport soils, though grounded ice can often protect banks from waves and currents. He also presented snow effects such as insulation lessening free-thaw and ground ice or snowmelt contributing to overland flows removing sediment. Finally, Gatto concluded that current knowledge to date was inadequate to create predictive equations and that a coordinated research effort in different regions was necessary for better understanding winter erosion processes.									
Gergel, S.E. 2002. Assessing cumulative impacts of levees and dams on floodplain ponds: a neutral-terrain model approach. Ecological Applications 12(6): 1740-1754.	2002	Dam and Levee effects on Floodplain Ponds	Peer Reviewed Basis Research	Wisconsin River, Wisconsin, USA	Temperate		Flood Control and Agriculture Dam		dams; flood magnitude; floodplain; levees; neutral-terrain model; temporary pond; wetlands; Wisconsin River.
Gergel (2002) developed and introduced a three-dimensional “neutral-terrain model” to examine cumulative impacts of levees and dams on the hydroperiod of ponds and wetlands in floodplains after flood events. Gergel sought to determine the relative influence of levees vs. dams on the duration and abundance of temporary ponds under varying flood-regimes, and determine if the effects of these two disturbances are additive, synergistic, or antagonistic. Levees decreased floodplain connectivity until it was breached (100-yr flood), then it followed a natural scenario. The dam decreased, increased, and had no effect on the floodplain connectivity depending upon flow magnitude. Synergism between the dam and levee existed at large flows (>100-yr flood), whereas when flows were lesser due to the attenuation of the dam this prevented the levees from breaching, demonstrating a negative feedback and response. Little can be garnered for our natural floodplain response studies.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Germanoski, Dru and Dale F. Ritter. 1988. Tributary Response to Local Base Level Lowering Below a Dam. Regulated Rivers: Research and Management 2: 11-24.	1988	Tributary Base Lowering	Peer reviewed Basic Research	Osage River, Missouri	temperate		hydroelectric		tributary incision, base level lowering, degradation, root armouring
Germanoski and Ritter (1998) developed a study that focused entirely on tributary response to river regulation by dam construction. In the 17 km below Bagnell Dam (Missouri), eight tributaries to the Osage River were evaluated. Because reconnaissance identified dam effects on tributaries to be greater near the dam, the study reach was chosen directly downstream of the dam. Bed material in the smaller tributaries consists of clay, silt and sand while coarse sand and gravel comprise that of larger tributaries. Hydrologically, the tributaries are mostly flashy with maximum discharges in spring and early summer and lows in late summer and early fall. On the main river, maximum annual peak discharge has remained roughly the same as that of pre-regulation flows. Trap efficiency of the dam has been estimated at greater than 90 percent. An increase in channel cross-sectional area by degradation and channel widening has resulted in local base level lowering on the main river. In this study, degradation was found to be the primary cause of tributary incision. The magnitude of incision was observed to be highest at tributary mouths. Root-armored knickpoints within tributaries has prevented entrenchment from continuing upstream in a single episode and resulted in stepped longitudinal profiles.									
Gorski, K., L.V. Van Den Bosch, K.E. Van de Wolfshaar, H. Middelkoop, L.A.J. Nagelkerke, O.V. Filippov, D.V. Zolotarev, S.V.Y. Yakovlev, A.E, Minin, H.V. Winter, J.J. De Leeuw, A.D. Buijse, and J.A.J. Verreth. 2012. Post-Damming Flow Regime Development in a Large Lowland River (Volga, Russian Federation): Implications for Floodplain Inundation and Fisheries. River Research and Applications 28, 1121-1134.	2012	Effect of hydrologic-regime on fish populations	Peer reviewed Basic Research	Volga, Russian Federation	temperate		reservoirs		Volga River, flood pulse, floodplain, damming, fish catch
Górski et al. (2012) evaluate the long-term discharge variability of the Volga River where multiple reservoirs have been installed in series. It was found that post-regulation average discharges were similar to pre-regulation discharges due to a reduction in maximum peak discharge and increase in minimum discharge. Damming has also resulted in a decrease in commercial fish catches in the main channel and floodplain lakes. A decrease in habitat variability in the floodplain resulted in more eurytopic fish species. It is unknown whether an increase in gibel carp in 1985 was related to flow regulation or other environmental factors (i.e., eutrophication of floodplain lakes) but it is likely that multiple factors contributed to the carp increase. A strong positive effect of flood magnitude however, was found with commercial fish yield in floodplain lakes. This suggests that discharge management that provides significant flooding in spring can preserve eco-hydrological function of the floodplain.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Graf, W.L. 1999. Dam Nation: a geographic census of American dams and their large-scale hydrologic impacts. Water Resources Research 35(4): 1305-1311.	1999	Extent of Dams in the United States	Peer Reviewed Basis Research	Continental United States of America			Dammed		None
Graf (1999) uses the National Inventory of Dams database to survey dams in the Continental United States for size and distribution, and impacts to the hydrologic cycle with respect to natural and human contexts. The basis for analysis is reservoir storage related to mean annual runoff, providing a relative measure of likely changes in flow regimes and downstream effects. This data are then compared to economic and demographic metrics of marginal cost of water and population density. Through the analysis it is found there are large ranges of storage capacity and economic value, with the greatest surface water impacts occurring in the Rocky Mountains, Great Plains, and the Southwest. Due to the relative recent construction of these dams, Graf states that downstream hydrologic and ecological effects are only being borne out now, and that this knowledge suggests the need to mitigate these impacts through retirement or operational changes to America's dams.									
Graf, W.L. 2006. Downstream hydrologic and geomorphic effects of large dams on American rivers. Geomorphology 79: 336-260.	2006	Downstream Hydrologic Effects of Dams	Peer Reviewed Basis Research	United States			Free Flowing and Regulated	5-10 km	Dams, Rivers, Hydrology, Fluvial Geomorphology, Aquatic and Riparian Habitats
Graf (2006) outlines the general physical changes that have occurred downstream of the Continental United States' 36 largest dams related to hydrologic and geomorphic effects, and their effects on riparian ecosystems and ultimately wildlife populations. The examination focuses on the hydrology-sediment regime, and the resulting suite of functional surfaces. Additionally, the paper details the process connection between hydrology-sediment regimes and the river landscape using two metrics: geomorphic complexity and standard active area. The greatest effect of dams is the reduction of peak flows, which on average were reduced by 67%. The other two statistically significant changes are minimum discharges and flow changes; minimum flows are 52% higher than unregulated reaches, the number of reversals is 34% in regulated reaches, and the up-ramp rates are 60% less than unregulated reaches. Geomorphically, downstream reaches are more incised with larger channels, fewer high flow channels, channel-side bars are less frequent, and there is 72% lesser standard active floodplain surface in regulated reaches with 37% less complexity.									
Grant, G.E., J.C. Schmidt, and S.L. Lewis. 2013. A geological framework for interpreting downstream effects of dams on rivers. In J.E. O'Connor and G.E. Grant. A Peculiar River. American Geophysical Union, Washington, D.C. doi: 10.1029/007WS13	2013	Geomorphic/geologic controls to dam response	Literature review and synthesis	Utah, Arizona, Oregon	Temperate		Dam - multiple		dam effects, sediment
Grant et al. (2013) developed an analytical framework based on two dimensionless variables, namely (S*) ratio of sediment supply below to that above the dam and (T*) the fractional change in frequency of sediment-transporting flows, to predict geomorphic responses to dams. They review approaches for assessing impacts of dams from existing literature and explore hypotheses that dams both modify the underlying geologically controlled transport regimes and act as a geological disturbance. They use examples from the Green, Colorado, and Deschutes Rivers to define geomorphic change in the context of geologic setting and river history. This model can be used to predict the magnitude and trend of downstream response to other dammed rivers and define systems where geologic controls may dominate responses to dams. Their model may be used to predict downstream trajectory of rivers in response to loss of specific grain size fractions and variable flow alterations.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41(8): 540-551.	1991	Riparian Area Function	Peer Reviewed Basis Research				Free Flowing		riparian zone
Gregory et al. (1991) provides a conceptual model of riparian zones through physical process, succession of terrestrial communities, formation of habitat, and the production of nutritional resources for aquatic ecosystems. The paper is a description of riparian zones, and their function. The riparian area is a zone of connection between the lotic zone and the upland zone. The lotic zone connects the montane headwaters with the lowland terrains, acting as an avenue of water, nutrients, sediment, particulates, and organism; the riparian area geomorphic form allows for these elements of the lotic zone to be transported laterally. The riparian zone is an area of high species richness and acts is a zone of high importance due to its linkage between terrestrial and aquatic zones. The riparian zone influences solar radiation, creates nutrient and particulate inputs as primary producers, acts as a retention mechanism for nutrients and organic matter, decomposes organic matter, and is habitat for aquatic invertebrates and vertebrates.									
Harza-Ebasco Susitna Joint Venture. 1984. Instream Ice Simulation Study. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 1986.	1984	Ice Dynamics	White Paper Report	Susitna	Boreal	50,764 sq km	Free Flowing	504 km	None
Harza-Ebasco (1984) utilized the ICECAL model to simulate Susitna River ice conditions using four winters of data from a cold winter (1971-1972), average winter ('81-'82), warm winter ('82-'83), and the warmest winter ('76-'77). The model was used to determine ice thickness, river stage, and freezeup/breakup timing for scenarios including (1) natural conditions, (2)Watana dam operating with 1996 energy demand, (3)Watana operating with 2001 energy demand, (4)Watana and Devil Canyon dams operating with 2002 energy demand, (5)Watana and Devil Canyon dams operating with 2020 energy demand, and finally (6)during the two years of filling the Watana reservoir. The coldest winter under natural conditions was predicted to have the greatest ice thickness and highest river stages while the warmest was predicted to have the thinnest ice and lowest river stages. Under scenario (2) freeze up was delayed 2-5 weeks from natural conditions and break up was 5-7 weeks earlier and the thickest ice and highest river stages were again predicted for the coldest year ('71-'72). With scenario (3) only slight differences from scenario (2) were observed in terms of ice thickness and river stage. Freeze up was 4-6 weeks later than natural with scenario (4), and breakup was 7-8 weeks earlier, and all winters besides the most severe ('71-'72) showed an average river stage of 1-4 feet higher than natural. Scenario (5) had a similar freeze up to scenario (4) but break up was estimated to be an additional 1-3 weeks earlier than (4) and during '71-'72 river stage would be 1-7 feet higher than natural while during '82-'83 it would only be 0-4 feet higher. Finally under the first year of scenario (6) freeze up would be 5-7 weeks later than natural, while breakup would be similar to natural. However during the second year of filling break up would also be 2-3 weeks later than natural. During the first and second year, river stage would be 0-5 feet and 0-3 feet lower than natural, respectively.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Harza-Ebasco Susitna Joint Venture. 1985. Survey of Experience in Operating Hydroelectric Projects in Cold Regions. Prepared for Alaska Power Authority. Susitna Hydroelectric Project FERC Project No. 7114. APA Document 2654.	1985	Hydroelectric Projects in Cold Regions	White-paper report	varies	Boreal	varies	hydroelectric	varies	None
Harza-Ebasco Susitna Joint Venture (1985) presents annotations of papers identified in a literature review of rivers that experience ice, a compilation of responses of hydroelectric operators in cold regions to a mail survey questionnaire, and a summary of a site visit to British Columbia Hydro and Peace River town on the Peace River. Four areas of interest for this paper include, reservoir and powerhouse operating procedures to mitigate ice jam related flooding, effects of reservoir ice cover and bank ice on animal crossing, management of reservoir ice cover to control cracking and its relation to animals, and ice-induced bank erosion in the reservoir. Conclusions based on questionnaires and the site visit are summarized and recommendations of the four environmental areas of interest are discussed for the Susitna River.									
Harza-Ebasco Susitna Joint Venture. 1985. Susitna River Ice Study. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 2747.	1985	Ice Effects	White Paper Report	Susitna	Boreal	50,764 sq km	Free Flowing	504 km	None
Harza-Ebasco Susitna Joint Venture (1985) studied the Middle and Lower Susitna Ice process through visual observation, ground measurements and aerial photography specific to the 1984 freeze-up and 1985 break-up. The 1984 freeze-up was unusual due to mild weather. Slush ice is critical in the freeze-up process as it forms anchor ice on the streambed. As the anchor ice increases in size it reaches a critical mass at which it becomes buoyant, detaches, and will float downstream. As the detached anchor ice travels downstream (ranging in 1-5 feet across) it will jam and create ice bridges that further create a positive feedback for freeze-up. Due to anchor ice's formation on the bottom of the stream, sediment will become frozen in place and be transported with the detached anchor ice. Break-up was unusually late in 1985, on May 24th. Break-up consists of a slow degradation of the ice cover into slush. As the process continues, openings form in the ice giving way to ice flows that travel downstream and become lodged behind ice dams. As the ice dams increase in size they cause micro-site floods. The 1985 break-up had little documented riparian effect. Ice jams occurred at RM 148, 145, 144, 139, 135, 131, 126.5, 122, 120.5, 119 and 113.									
Harza-Ebasco Susitna Joint Venture. 1986. Impacts Assessment: Downstream Vegetation. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 3362.	1986	Susitna-Watana Effects on Riparian Vegetation	White Paper Report	Susitna	Boreal	50,764 sq km	Free Flowing	504 km	None
Harza-Ebasco Susitna Joint Venture (1986) quantify the extent of changes of both early and mature vegetation downstream of Devil's Canyon, estimate the amount the floodplain that will experience these changes, and do this in acres of various riparian vegetation communities. The study heavily relies upon elevation from the edge of the river to determine active zones, where, as these zones are further from the river the successional stage progresses. The active zone is broken into four bands, each representing a different seral stage of the Susitna riparian forest. For the middle river, at the end of the license period it is hypothesized that the early and middle seral communities will increase 20%, and after 100 years there will be a 35% reduction in these communities; this is due to there no longer being conditions for seedling establishment resulting in a loss of these ecosystem stages. For the lower river the same trend is hypothesized, however with more expansion of riparian habitat since there are large gravel bars just below the active zone that will be accessed with reduced flows.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Healy, Dan and F.E. Hicks. 2007. Experimental Study of Ice Jam Thickening under Dynamic Flow Conditions. Journal of Cold Regions Engineering 21, no. 3: 72-91.	2007	Ice Processes	Peer reviewed Basic Research						Ice flow, steady flow, thickness, hydrodynamics, rivers, hydraulics
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Healy and Hicks (2007) studied ice jam accumulation subjected to significant flow increases. The study was developed in an effort to further understand how dynamic flow conditions (often from hydropeaking operations) may affect downstream ice jams and associated ice-jam flooding. Experiments took place in a 32 meter long rectangular flume with a constant slope for all experimental runs. A free-floating piece of plywood was used to simulate an intact ice cover. A coarse wire mesh on the sides of the flume was used to simulate an “ice-ice” shear interface that was more representative of natural conditions. A total of 40 simulations were performed. Observations suggest that final stable accumulations correlate with the wide jams under steady state conditions jam stability equation. Further, slightly thicker accumulations were observed at steady carrier flow conditions compared to sudden flow increases at a similar discharge. The wire mesh did not appear to have a significant effect on the simulations compared to no mesh.									
Hjort, J., and M. Luoto. 2009. Interaction of geomorphic and ecologic features across altitudinal zones in a Subarctic landscape. Geomorphology 112: 324-333.	2009	Geomorphic and Ecologic Effects	Peer Reviewed Basis Research	Finland - 300km north of the Arctic Circle	Boreal	600 sq km	Not a Littoral System		Biogeomorphology, cryoturbation, treeline, alpine, hierarchical partitioning, variation partitioning
Hjort and Luoto (2009) assess the interactions of plant communities and cryoturbation along altitudinal zones seeking to find feedbacks and potential effects of physical and biological characteristics of a subarctic landscape. Data was collected for topographical features, soil and vegetation characteristics in three zones – forested, transition, and alpine. Results showed that vegetation factors, especially canopy cover of field-layer vegetation and aboveground biomass, were the most important environmental variables affecting the occurrence of cryoturbation, demonstrating a positive relationship. Tree canopy cover showed a negative relationship with cryoturbation and periglacial process. Causality of vegetation and periglacial activity cannot be determined, but it is recognized there is a significant relationship between the two. Conclusions were then used to determine the effects of climate change upon these processes, concluding the advance of treeline in elevation will promote further periglacial process in subarctic regions.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Hupp, C.R., A.R. Pierce, and G.B. Noe. 2009. Floodplain geomorphic processes and environmental impacts of human alteration along coastal plain rivers, USA. Wetlands 29(2): 413–429.	2009	Sediment transport	Literature review and synthesis	SE United States	Semi-arid	varies	3 dams: 1 flood-control and 2 small hydroelectric	varies	channelization, dams, ecosystem services, fluvial geomorphology, sediment
Hupp et al. (2009) uses three case studies to characterize the effect of dramatic hydrologic alterations, including dam construction, on geomorphic processes and sediment deposition. They identify critical fluvial parameters (e.g., stream gradient, grain-size, and hydrography) and spatial and temporal sediment deposition/erosion process trajectories that should facilitate management efforts. They describe three important unifying concepts 1) hydraulic connectivity between streamflow and the riparian zone, 2) spatial migration of major channel features such as knickpoints and 3) dynamic equilibrium in fluvial systems which balances entrainment, transport and storage of sediment. Responses to damming are described for the Roanoke River, NC where dams have eliminated high-magnitude flooding and increased the frequency of moderate and flow pulses. They show evidence that flow regulation with loss of peak flows has resulted in alterations to overbank flooding and thus a shift in sediment deposition distribution to low elevation backwater areas rather than on natural levees along the channel. This leads to a higher floodplain elevation with continued incision of the channel and channel widening as the floodplain traps less sediment over time. This elevated and increasingly uniform floodplain may have decreased biodiversity through time. They observe that erosion on cut banks and in many straight reaches appears active, but there is limited deposition and point-bar development in the channel.									
Inter-Fluve, Inc. June 2004. Cooper Creek Sediment and Geomorphology Investigation Final Report. Cooper Lake Project (FERC No. 2170). Prepared for HDR Alaska, Inc.	2004		White-paper report	Cooper Creek, Alaska	Boreal		hydroelectric		None
As a component of the Cooper Creek Instream Flow Study, the sediment and geomorphology of Copper Creek is characterized in order to assess the suitability of spawning habitat for salmonids under present and future conditions. Cooper Lake, which previously discharged to Cooper Creek, was dammed, resulting in the complete diversion of outflow by 1961. This report includes a sediment transport analysis as well as a qualitative assessment of Cooper Creek geomorphic conditions to identify whether the channel has fully adjusted to the post-regulation hydrologic regime and what types of changes may occur under the current and future flow regimes. Embedment sampling, surface and subsurface bed-material sampling were performed at selected sites in Cooper Creek. Conclusions are drawn for different reaches of Cooper Creek. Downstream of the dam appears to be a relatively stable reach and is predicted to remain as such. Downstream of the major tributary (Stetson Creek) is roughly in equilibrium with the flow and sediment regimes and is predicted to have slow geomorphic change driven by large flood events. Geomorphic findings suggest Cooper Creek, upstream of its major tributary, has adjusted to the changed flow regime through a filling of valley floor with upslope colluvial material. Through the canyon below the confluence of Stetson Creek, bed material remains mobile due to its confined channel geometry, steeper slopes and additional flow from Stetson Creek. In the reach near the confluence of the Kenai River, Cooper Creek is confined to a single channel but appears to be controlled by the morphology of past mining disturbance. The report concludes the existing hydrology in the reaches downstream of the Stetson Creek confluence appear to still be capable of transporting the current sediment regime through most of the channel.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Jamieson, B., and J. Braatne. 2001. The impact of flow regulation on cottonwood forests along the Kootenai River in Idaho, Montana and British Columbia. Technical Report 2000-2001 DOE/BP-00000005-2. Bonneville Power Corporation, Portland, OR.	2001	Cottonwood Forest Health Related to Hydro-regulation	White Paper	Kootenai River, Idaho, Montana and Southern BC	Semi-Arid	36000 sq km	Hydroelectric and Flood Control	775 km	load-following, dam effects, cottonwood
Jamieson and Braatne (2001) determine the health of the Kootenai River to assist in planning restoration efforts coupled with salmon restoration. The report is highly specific to the stream studied, however general trends are found. Downstream of the reservoir human impacts were much more extensive due to regulated flows and the subsequent encroachment of vegetation onto the lateral margins due to flow regulation. In 1991 and 2000 spring flow releases occurred to encourage White Sturgeon spawning, due to these increased flows there was a cottonwood recruitment response seen downstream of the reservoir. Restoration efforts are suggested using the recruitment box model as a framework to plan hydrograph recession. The Libby dam (the dam in the study) operates as load-following at times.									
Jansson, Roland, Christer Nilsson, Mats Dynesius, and Elisabet Andersson. 2000. Effects of River Regulation on River-Margin Vegetation: A Comparison of Eight Boreal Rivers. Ecological Applications 10, no. 1: 203-224.	2000	Dam effect on vegetation	Peer reviewed Basic Research	varies	Boreal		free-flowing and dammed		dams; dispersal capacity of river-margin plants; disturbance: fragmentation; plant species richness vs. water-level regime; reservoirs; riparian vegetation; river regulation, effects on vegetation; seed dispersal; Sweden, northern; vegetative dispersal.
Jansson et al. (2000) studied the effects of river regulation on river-margin vegetation in boreal regions. Of the studied rivers, four were free-flowing and four regulated. All rivers were located in northern Sweden. Species diversity per site was compared between free-flowing and regulated rivers. River-margin vegetation was found to respond differently to different hydrologic regimes. Run-of-river impoundments were found to be most similar to unregulated rivers with a similar number of species but a lower overall plant cover per site. The impact of regulation with reduced discharge was unclear due to evidence of lowered and un-lowered variables compared to unregulated rivers compounded with low statistical power due to small sample sizes. In testing plant species according to dispersal mechanisms, evidence suggests dispersal ability is necessary for post-regulation persistence. Further it was found that water dispersal may be an important dispersal mechanism despite fragmentation due to dams. Overall high plant species richness and cover was attributed to clay and silt in river-margin soil, location of pre-regulation river-margin vegetation, low altitudes, long growing seasons, and non-reservoir sites.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Jansson, R., C. Nilsson, and B. Renofalt. 2000. Fragmentation of riparian floras in rivers with multiple dams. Ecology 81(4): 899-903.	2000	Vegetation dispersal	Peer Reviewed Basic Research	Northern Sweden	Boreal	multiple	Dammed and free flowing	multiple	corridor functions; dams as barriers to plant dispersal; dams vs. ecological riparian continuity; fragmentation; hydrochory; plant species composition and dispersal; regulated rivers; riparian vegetation; seed dispersal; Sweden; vegetative dispersal.
Jansson et al. (2004) studied 20 impoundments on a variety of dammed rivers in Northern Sweden and compared their floristic composition to impoundments with similar environmental characteristics and to free-flowing rivers. They found that floristic similarity was higher within impoundments than between and that there was no significant floristic variation along free-flowing rivers; evidence that dams caused dispersal limitation for riparian vegetation. Dams mainly limited dispersal of species with diasporas that had poor floating abilities. Overall, ecological continuity is not only lost within the river channel via damming, but the adjacent riparian corridor is impacted by vegetation dispersal limitation.									
Jansson, R., U. Zinko, D.M. Merritt, and C. Nilsson. 2005. Hydrochory increases riparian plant species richness: a comparison between a free-flowing and a regulated river. Journal of Ecology 93: 1094-1103.	2005	Hydrochory Between Free and Regulated Rivers	Peer Reviewed Basis Research	Ume and Vindel Rivers, Northern Sweden	Boreal		Free Flowing and Regulated		dams, fragmentation, hydrochory, riparian vegetation, river continuum, seed dispersal, seed germination, Sweden, vascular plants, vegetative dispersal
Jansson et al. (2005) conclude fluvial disturbance and plant dispersal by water is important for enhancing species richness in riparian plant communities. No evidence showed that dams reduce the abundance and diversity of water-dispersed propagules, and hydrochory for plant colonization was similar between a free-flowing and regulated river. The number of colonizing individuals didn't differ significantly with flooding, but hydrochory increased the number of colonizing species per year and plot by 40-200%. The pool of colonizing species was 36-58% greater per year for flooded than unflooded plots, and flooding was more important than elevation in determining diversity of colonizers. Differences in cumulative species richness between flooded and unflooded plots was as large as that between plots for the two environments. This supports the hypothesis that hydrochory is important for the diversity of colonizing species at the reach scale, and outweighs the mortality induced by flooding. Long-distance floating of species didn't significantly show any benefit over short-distance floating species.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Jeffries, R., S.E. Darby, and D.A. Sear. 2003. The influence of vegetation and organic debris on flood-plain sediment dynamics: case study of a low-order stream in the New Forest, England. Geomorphology 51: 61-80.	2003	Hydrologic and Riparian Response to Large Woody Debris	Peer Reviewed Basis Research	Highland Water, England	Temperate	12.7 sq km	Free Flowing		floodplain, overbank, sediment, forest, vegetation, large woody debris
Jeffries et al. (2003) establish conceptual models of floodplain evolution relating water, sediment and vegetation, and their relationship with large woody debris (LWD). A LWD dam was studied on a low-energy, third-order stream, and results showed a local increase in the frequency and extent of overbank flows, and the impacts of sedimentation. During the study periodic overbank flows occurred 41.5% of the time, as compared to 0.2% in the adjacent dam-free section. Micro- and mesoscale accretion patterns were studied with a DEM of floodplain topography, vegetation and LWD, and the amount of overbank sediment deposition was correlated most loosely with flood hydrology and sediment input.									
Johansson, M.E., and C. Nilsson. 2002. Responses of riparian plants to flooding in free-flowing and regulated boreal rivers: an experimental study. Journal of Applied Ecology 39: 971-986.	2002	Riparian Response to Flow Alteration	Peer Reviewed Basis Research	Northern Sweden	Boreal		Free Flowing and Regulated		*Betula pubescens*, *Carex acuta*, *Filipendula ulmaria*, *Leontodon autumnalis*, plant growth rate, PLS regression, river regulation.
Johansson and Nilsson (2002) compared the growth rate and survivorship of four transplanted riparian species on free-flowing and regulated rivers to compare water-level regimes. The study spanned two years, and was said to have had too short of a study-period, and too much site- and species-variability, to correlate water levels with plant success and survivorship. Regardless, findings showed *Betula* sp. and *Filipendula* sp. had higher mean proportional growth rates at free-flowing sites versus regulated sites, whereas *Carex* sp. and *Leontodon* sp. showed no consistent difference. Elevation gradients showed patterns in accordance with natural distribution patters, while all species were able to survive in elevations below typical natural occurrence. Flood duration and frequency showed a negative feedback to plant growth, and early flooding determined performance to a high degree where the first summer flood was ranked as the most important variable among all models for all species.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Johnson, W.C. 2000. Tree recruitment and survival in rivers: influence of hydrological processes. Hydrological Processes 14: 3051-3047.	2000	Seedling recruitment and survival	Peer Reviewed Basis Research	Platte River, Nebraska	Semi-arid		Dammed		None
Johnson (2000) used a field demographic approach over a 14 year period on the Platte River in Nebraska to determine how stream flow and seedling mortality interact in the current and historical patterns of woodland encroachment into the active channel. Seedlings were consistently most successful on fresh alluvium in the active channel and on particular landforms, including sand bars isolated in braided river sections, point bars in small meandering channels, and at the downstream ends or connections between sandbars in braided sections. Most germination occurred in June and streamflows during this time determined where seedling recruitment occurred vertically. Thus, historically, June streamflow (magnitude and hydrograph shape) correlated with woodland expansion. Factors contributing to seedling mortality are discussed in detail by season. Overall flow fluctuation (mainly in summer), erosion, sedimentation, drought, and ice are the main contributors to mortality. Most mortality occurs in either winter (for the first part of the study) or summer (for the second). Drought contributes least frequently to mortality (once every seven years) while streamflow contributes most (annually). It appears that the Platte River is currently in equilibrium between seedling recruitment and mortality so that the encroachment of woodland is balanced with the changes in active channel size. The primary management concern on this river is for bird habitat, and Johnson suggests that since the channel is currently stable there may be little need for destruction of vegetation to increase active channel and thereby increase bird habitat. He does however posture that flows could be augmented during summer periods to remove vegetation and decrease woodland encroachment if need be.									
Johnson, W.C., M.D. Dixon, M.L. Scorr, L. Rabbe, G. Larson, M. Volke, and B. Werner. 2012. Forty years of vegetation change on the Missouri River floodplain. BioScience 62(2): 123-135.	2012	Dam Effects on Vegetation	Peer Reviewed Basic Research	North Dakota	Semi-arid		Dammed	166 km	riparian, cottonwood, deltas, restoration, reservoirs
Johnson et al. (2012) revisited two hypothesis about the long-term effects of damming on the riparian vegetation of the Missouri river that were developed during a previous study in 1976. The authors hypothesized that cottonwood regeneration would be majorly reduced due to decreases in peak flows and channel dynamics, and that a decrease in diversity of late successional forest stands would occur due to patterns in reproduction of the three main late successional tree species. They then discussed how the dam has changed the study area through changes in hydrologic and sediment regime, riverbed elevation, land and water cover, and a reservoir delta. After resurveying the same area studied in 1969 and 1970 the authors concluded that cottonwood trees are slowly on their way out along this river and that due to decreases in elm and box elder and increases in green ash, succession has slowed and diversity of late successional stands decreased, with green ash becoming the dominant tree. Overall both hypotheses from 1976 were supported and the authors warn that this ecosystem is becoming severely degraded with limited possibilities for restoration unless action is taken.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Johnson, W.C., M.D. Dixon, R. Simons, S. Jenson, and K. Larson. 1995. Mapping the response of riparian vegetation to possible flow reductions in the Snake River, Idaho. Geomorphology 13: 159-173.	1995	Dam effects on vegetation	Peer Reviewed Basic Research	Snake River, Idaho	Semi-arid		Dammed		None
Johnson et al. (1995) modeled how riparian vegetation would be affected by flow alteration on the Snake River in Idaho. The horizontal, vertical, and temporal patters of riparian vegetation are affected by physical processes along the river and riparian vegetation also influences hydrogeomorphic processes. Along the Snake River riparian vegetation could be divided into five zones along an elevational gradient from wettest to driest: emergent, forb-shrub, tree, transitional grass-shrub, and upland shrub. These zones spanned on average 8 ft out from rivers edge. With lower flows, models showed that emergent communities would succeed into forb-shrub communities and newly exposed areas would develop into emergent vegetation communities. The largest area affected by these changes would be near islands, although overall most of the river is narrow and deep and there would be minimal potential for vegetation expansion into the channel. In general the authors noted four ecological consequences of reducing flows on this river: an increase in riparian vegetation area with vegetation mortality at upper elevation zones offsetting this increase initially, an increase in sedimentation due to vegetation encroachment in shallow channels leading to a loss of shallow active channel, an increase in dominance by exotic species, and increased predation on nesting wetland birds due to loss of deepwater barriers around nesting zones.									
Keeyask Hydropower Limited Partnership. 2012. Environmental Impact Statement. http://keeyask.com/wp/the-project/environmental-assessment-process/eis.	2012		White-paper report	Nelson River, Manitoba	Boreal		hydroelectric		None
Keeyask Hydropower Limited Partnership (2012) evaluated hydroelectric development on the Nelson River in northern Manitoba, Canada. The Environmental Impact Statement (EIS) consists of an executive summary, response to the EIS guidelines, the Cree Nations Environmental Evaluation Reports as well as six supporting volumes including Project Description, Public Involvement, Physical Environment (i.e., Surface Water and Ice Regimes, Physiography, Shoreline Erosion Processes, Sedimentation, Groundwater, Surface Water Temperature and Dissolved Oxygen, Debris, Sensitivity of Effects Assessment to Climate Change, and Effects of the Environment on the Project), Aquatic Environment (i.e., Water and Sediment Quality, Aquatic Habitat, Lower Trophic Levels, Fish Community, Lake Sturgeon, Fish Quality, Sensitivity of Effects Assessment to Climate Change), Terrestrial Environment (i.e., Habitat and Ecosystems, Terrestrial Plants, Terrestrial Invertebrates, Amphibians and Reptiles, Birds, Mammals, and Wildlife and Mercury), and Socio-Economic Environment, Resource Use and Heritage Resources.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Kellerhals, R. and D. Gill. 1973. Observed and potential downstream effects of large storage projects in northern Canada. Commission Internationale des Grandes Barrages. Onzieme Congres des Grands Barrages. Madrid, Spain, 1973.	1973	Downstream effects of dams	Literature Review	Northern Canada			Dammed		None
Kellerhals and Gill (1973) discussed the detrimental downstream effect of regulation on northern Canadian rivers. They presented the natural processes inherent on northern Canadian rivers including the three typical flow regimes, the fact that most of these rivers have low sediment loads, and that ice influences flow for six to seven months of the year with breakup being the most significant part of the yearly ice regime. Short term physical effects of regulation include alteration of flow and water levels usually via peaking or reduced peak flows and increased minimums, changes to ice effects and timing of ice events, and alteration of mesoclimate (generally cooling). Long term physical effects include sedimentation problems (less so than on more alluvial rivers), however the ability of Canadian gravel rivers to transport bed material would decrease. Other long term effects also include tributary degradation and a likely increase in permafrost due to lower water levels and decreased flooding and siltation. Ecological effects include a reduced biological productivity of riparian plant communities due to decreased disturbance and thus succession into older soil-vegetation complexes. Habitat for waterfowl, aquatic mammals, and spawning fish would also be modified in negative ways such as reduced access to food, increased predation risk, and decreased suitable habitat area and accessibility. Finally, social and economic effects include the decrease of traditional hunting, fishing, and trapping as well as a decreased potential for future recreation based economic activity. Navigation on northern rivers is also decreased as a result of lower water levels and increased ice cover.									
Konrad, C.P., J.D. Olden, D.A. Lytle, T.S. Melis, J.C. Schmidt, E.N. Bray, M.C. Freeman, K.B. Gido, N.P. Hemphill, M.J. Kennard, L.E. McMullen, M.C. Mims, M. Pyron, C.T. Robinson, and J.G. Williams. 2011. Large-scale flow experiments for managing river systems. BioScience 61(12): 948-959.	2011	Large-scale flow experiments	Literature review and synthesis				Dam- multiple		rivers, flow experiments, dams, ecosystem management
Konrad et al. (2011) reviewed over 40 studies on large-scale flow experiments and discussed the ways these experiments should be conducted in the future. There are five challenges that flow manipulations face in terms of classical experimentation standards. Challenges to flow experiments include things such as manipulations being inseparable from social context, experimental treatments and responses spanning multiple time scales, flow experiments are part of a large network and connected to it in ways that are difficult to tease apart, other factors caused by dams may be limiting aside from river flow, and different taxa respond differently to manipulations so effects may be difficult to determine. Five principals are addressed that can advance scientific understanding and management goals when the five above challenges are met. Scientists need to understand that experiments are for learning not necessarily managing, experiments can be integrated with modeling and monitoring if long term research cannot be done, spatial observations need to be used to understand the extent and gradients of experimental treatments and responses, treatments are best if well-defined and repeated over time, and finally other management actions influence flow experiments and scientists need to be aware of this. The authors wrap-up by stating that large-scale flow experiments are difficult but necessary for our understanding and management of river systems.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Kraft, Clifford E., Rebecca L. Schneider, and Dana R. Warren. 2002. Ice storm impacts on woody debris and debris dam formation in northeastern U.S. streams. Canadian Journal of Fish Aquatic Sciences 59: 1677-1684.	2002	Ice effects	Peer reviewed Basic Research	New York river basins	temperate		free flowing		None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Clifford, Schneider and Warren (2002) studied the role of ice storm effects on the recruitment of in-channel and out-of-channel woody debris. Forty-three first-, second- and third- order reaches within 5 watersheds east of the Adirondack Mountains in New York were surveyed. All streams had pool-cascade dominated flow, cobble-dominated substrate and relatively high gradient. At each identified transect within each study reach, bankfull width, water depth, substrate composition and woody debris data were collected. Woody debris data included tree canopy damage, extent of canopy damage, dimensions of debris dams (if greater than 1 meter long in any dimension), and relative age of key member in debris jam. Debris dams surveyed after the 1998 ice storm were evaluated for stream function. Results found that the 1998 ice storm was responsible for significant input of woody debris into the stream system. Woody debris input was also found to be correlated to the relative age of the forest margin (i.e., higher input from older trees compared to young trees). Woody debris was not found to increase pool formation, as is often the case in western rivers.									
Krasny, M.E., K.A. Vogt, and J.C. Zasada. 1988. Establishment of four Salicaceae species on river bars in Interior Alaska. Holarctic Ecology 11(3): 210-219.	1988	Seed dispersal, germination, and vegetative reproduction	Peer Reviewed Basic Research	Tanana River, AK	Boreal				None
Krasny et al. (1988) explored the different sexual and asexual reproductive methods of three common floodplain species*:* *Populus balsamifera*, *Salix alaxensis*, and *Salix interior*, and one species frequently excluded from the floodplain*:* *Populus tremuloides*. Overall, lab and field tests showed few differences between species in germination based on moisture, osmotic potential, electrical conductance, or soil texture. Therefore, differential seed germination does not appear to account for the differences in the distribution of the four study species, and *P. tremuloides* was not more sensitive to high salt concentrations as others hypothesized. However, differences in seed dispersal between *Salix* spp. and *P. tremuloides* may explain differences in establishment patterns. Seeds of *Salix* spp. can be dispersed long ranges by air or water, they have pappus surrounding them which favors their retention on wet sites, and they have the ability to germinate underwater. Additionally, *Salix* spp. and *P. balsamifera* are able to reproduce vegetatively into areas with unfavorable seed germination characteristics through root suckering (not *S. alaxensis*), stem sprouting, and rooting of plant fragments (root and shoot fragments for *P. balsamifera* and *S. interior*, and shoot fragments for *S. alaxensis*), while *P. tremuloides* cannot reproduce well by any of these methods. Vegetative reproduction likely offers the best explanation for how the three floodplain species are distributed and the exclusion of *P. tremuloides* from the floodplain.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Kreutzweiser, David P., Kevin P. Good, and Trent M. Sutton. 2005. Large woody debris characteristics and contributions to pool formation in forest streams of the Boreal Shield. Canadian Journal of Forest Restoration 35: 1213-1223.	2005	Large Woody Debris	Peer reviewed Basic Research	Steams in the Boreal Shield forest	Boreal		free flowing		None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Kreutzweiser, Good and Sutton (2005) surveyed large woody debris (LWD) in rivers of the Boreal Shield (spans between northwestern Saskatchewan and Newfoundland). LWD data collection efforts included measuring diameter, total length, in-channel length and mid-channel length. Further, LWD input sources were determined and pieces were ranked on a scoring procedure by Davis et al. (2001) based on position and stability. Study results found inputs, characteristics and functions of LWD in the forested Boreal Shield streams to differ from those found in other North American streams. Mainly, LWD was found to be less abundant, less stable, smaller and therefore less functional than other studied streams (particularly in the northwest United States). The channel morphology of the studied streams was found not to be influenced by LWD. Rather coarse bed-material of the streams contributed to instability of LWD pieces, increasing the possibility for fluvial transport. Caution is offered for extrapolating study results to more western streams that typically contribute larger and more stable LWD.									
Landry, R., A.A. Assani, and S. Biron. 2013. The management modes of seasonal floods and their impact on the relationship between climate and streamflow downstream from dams in Quebec (Canada). River Research and Applications, DOI: 10.1002/rra.2644.	2013	Climate and hydrologic regime	Peer reviewed Basic Research	Ouareau River and Matawin River, Quebec	Boreal	5770 km^2	hydroelectric		daily extreme flows, flood management mode, temperature, precipitation, dams, Quebec
Landry, Assani and Biron (2013) studied the relationship of climate on interannual variability of large floods downstream from dams on two rivers in Québec. The study evaluates the role of seasonal flood management, one on the Ouareau River and another on the Matawin River, and its effect on climate and stream flow downstream from dams. The study found the Ouareau River to have a natural-type flow regime downstream of the Rawdon dam where seasonal floods in the unregulated reaches upstream of the dam were the same as those downstream of the dam. On the Matawin River there is an inversion-type flow regime downstream of Matawin dam, and the seasonal floods experienced in the upper unregulated reaches of the river do not occur in the same season as those downstream of the dam. Thus, there is no correlation between climate and the flows downstream from Matawin dam. The study found the mode of management of seasonal floods to be the primary factor affecting the climate-streamflow relationship. Furthermore, relationship between climate and the magnitude of extreme seasonal floods is dependent on the extent of changes affecting flood regimes and temporal scale of streamflow analysis. That is, the effect of flood management will be less dominant on the annual scale as precipitation downstream dampens the effect of regulation on streamflow.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Langedal, Marianne. 1997. The influence of a large anthropogenic sediment source on the fluvial geomorphology of the Knabeåna—Kvina rivers, Norway. Geomorphology 19: 117-132.	1997	Sediment Transport and Sedimentation	Peer reviewed Basic Research	Knabeana River, Norway	Boreal		dam (contaminated sediment entrapment)		sediment, stream transport, provenance, fluvial sedimentation, geomorphology, fluvial features, floodplains, molybdenum, tailings
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Langedal (1997) studied the fluvial geomorphology of a reach of the Knabeana-Kvina rivers (Norway) downstream of a reservoir with contaminated sediments from mining. Of particular focus was the concentrations of molybdenum in the sediments. A significant portion of tailings was found to be stored as sandbars in a low-gradient reach below the dam. The sediments remain stable during normal floods however sediments in steeper reaches may mobilize during frequent large floods. Weirs, which create artificial low-gradient zones, are suggested as a mitigation technique to prevent further dispersal of contaminated sediments.									
Leyer, I. 2005. Predicting Plant Species' Responses to River Regulation: The Rold of Water Level Fluctuations. Journal of Applied Ecology 42: 239-250.	2005	Riparian Response to Flow Alteration	Peer Reviewed Basis Research	Elbe River, Germany	Temperate	148,200 sq km	Transportation Locks	1096 km	dyke, flooding, floodplain, grassland species, levee, logistic regression, regulated river
Leyer (2005) responds to the loss of fluctuating water tables in regulated rivers, and assesses the response and shift of 30 common grassland species to soil moisture and water level fluctuations. A model is developed correlating species presence to average groundwater level and water level fluctuations. The study was broken into floodplains with levees and natural floodplains. The majority of species significantly related to average groundwater level, but the response curves were very different for leveed and natural floodplains. The majority of species responded to groundwater level, where in natural floodplains species at high elevations occurred at lower elevations in the leveed system, and vice-versa. Half of the species preferred either the natural or the leveed floodplain. Water level fluctuation was of lesser importance for most species, however when added into the model it increased precision for 25 of the 30 selected species, especially when comparing species that prefer differing elevations of the floodplain in the natural and leveed surfaces.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Leyer, I. 2006. Dispersal, diversity and distribution patterns in pioneer vegetation: The role of river-floodplain connectivity. Journal of Vegetation Science 17:407-416.	2006	Vegetation dispersal and connectivity	Peer Reviewed Basis Research	Elbe River, Germany	Temperate	148,200 sq km	Dyke	1096 km	Dyke; Experimental design; Hydrochory; Levée; Seedling; Semi-terrestrial habitat; Soil seed bank; Species richness; Water body.
Leyer (2006) experimentally tested the significance of three different methods of seed dispersal in four types of water bodies of decreasing connectivity along the Middle Elbe River in Germany. Dykes in this area and much of central Europe have almost completely cut off connectivity between rivers and floodplain water bodies so the author wanted to evaluate the importance of connectivity for diaspore dispersal. Overall the number of seedlings as well as species richness increased from very low in areas that were permanently isolated behind dykes, to areas temporarily connected during floods, to almost permanently connected river side arms, to high in the main river and river margin. Water dispersal was the most important mechanism, followed by the seed bank, followed by very little dispersal by wind and animals. Several properties of species including seed buoyancy, rooting ability in the riparian zone, and amount of seed production were discussed as possible reasons for the observed distribution patterns. Leyer determined that water dispersal limitation due to dyke presence resulted in the absence of many species in isolated habitats and promoted dyke relocation to increase connectivity.									
Leyer, I., E. Mosner and B. Lehmann. 2012. Managing floodplain-forest restoration in European river landscapes combining ecological and flood-protection issues. Ecological Applications 22(1): 240-249.	2012	Floodplain Forest Restoration	Peer Reviewed Basis Research	Elbe River, Germany	Temperate	148,200 sq km	Regulated	13 km	floodwater management; habitat-distribution model; hydraulic modeling; Middle Elbe River, Germany; riparian woodlands; river-basin management; *Salix*; softwood forest; willow reforestation
Leyer et al. (2012) provide a tool (a two-dimensional model) to improve floodplain-forest restoration under the observance of flood-protection. The approach uses iterative modeling on the basis of ecology and habitat distribution modules to determine suitable sites, and hydraulic modeling to limit flooding techniques to determine optimum restoration sites. Due to modeling a system with large amounts of human infrastructure, the concern to avoid flooding from increased hydrologic resistance and subsequent backwatering was a large concern of the paper. The model was used to select sites with suitable habitat as well as minimal backwatering effect. The ecologically suitable sites were not selected for natural recruitment suitability, rather planting. With restoration efforts such as these, the effects will be the benefit of improved habitat, the economic value of the wood, and attenuation of flood-effects.									

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<tr><th>Citation</th><th>Year</th><th>Topic</th><th>Source Type</th><th>Location</th><th>Habitat Type</th><th>Watershed Size</th><th>Hydrologic Regime</th><th>River Length</th><th>Key words</th></tr>
<tr><td>LGL Alaska Research Associates, Inc. 1983. Environmental Studies - Subtask 7.12: Plant Ecology Studies Phase II. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 3516.</td><td>1984</td><td>Plant Ecology</td><td>White Paper</td><td>Susitna</td><td>Boreal</td><td>50,764 sq km</td><td>Free Flowing</td><td>504 km</td><td>None</td></tr>
<tr><td colspan="10">LGL Alaska Research Associates (1984) conduct moose browse inventory, plant phenology studies for increased nutrient content for cow moose in the Spring, and a pre-burn study in response to a prescribed fire. The browse inventory consisted of a botanical survey, where shrubs, forbs, graminoids, and lichens were the most important vegetation types for moose spring and summer food habits. For shrubs, it was found moose grazed on individuals averaging 147% larger than average individuals. The phenology study was initiated to evaluate forage availability for cow moose during parturition, however results showed no significant trend in behavior. The authors hypothesize the mesoclimatic effects of the reservoir may cause an earlier greening of the banks allowing for greater nutrient availability. The botanical component of the pre-burn study demonstrated that cover of herbaceous plants is inversely proportional to shrub density. Conclusions of the fire study determined that fire could increase potential Open White Spruce, Open Black Spruce and Woodland White Spruce community types as moose habitat, since shrubs that are major foods for moose exist in these types.</td></tr>
<tr><td>Lignon, F.K., W.E. Dietrich, and W.J. Trush. 1995. Downstream ecological effects of dams. BioScience 45(3): 183-192.</td><td>1995</td><td>Dam Impacts on Geomorphology</td><td>Literature review and synthesis</td><td></td><td></td><td></td><td>Dam - multiple</td><td></td><td>dam effects, wildlife</td></tr>
<tr><td colspan="10">Lignon et al. (1995) explained the importance of using a geomorphic approach to understand and decrease the negative impacts of dams on rivers. They presented three case studies from Oregon, Georgia, and New Zealand where rivers have been dammed. In each case they described how changes in river geomorphology negatively affected biological processes or habitats for fish or birds. They concluded that the geomorphic responses downstream of a dam can widely vary, but in all cases they have a range of ecological consequences. They presented an assessment procedure for use before building a dam to determine geomorphic impacts and how to incorporate a biological perspective. Finally, they stated that although each river is unique, water releases and sediment must be mitigated after building a dam to preserve the pre-dam geomorphology as much as possible.</td></tr>
<tr><td>Liu, Baozhong, Daqing Yang, Baisheng Ye, and Svetlana Berezovskaya. 2005. Long-term open-water season stream temperature variations and changes over Lena River Basin in Siberia. Global and Planetary Change 48: 96-111.</td><td>2005</td><td></td><td>Peer reviewed Basic Research</td><td>Lena River, Siberia</td><td>Boreal</td><td>2,430,000 km^2</td><td>reservoir</td><td></td><td>Lena River; stream temperature; regime and change; reservoir impacts; Arctic Ocean</td></tr>
<tr><td colspan="10">Liu et al. (2005) analyzed long-term stream temperature records within the Lena River Watershed in order to determine water temperature regimes and identify stream temperature changes due to regulation or environmental factors. Results show the open water season is divided into three temperature stages. The early open water season exhibited increasing temperatures, the mid-open water season exhibited stable temperatures, and the late open water season exhibited decreasing temperatures. This has resulted in a shift towards an earlier warmer stream temperature season since regulation. This warming may also be due to an earlier snowmelt throughout the Lena River basin. The late open water season temperature appears to have not been significantly affected by regulation. Temperature variations at the Lena River outlet (drains north) exhibit colder temperatures than the southern, more upstream basins, indicating latitudinal difference in climate influence. These results indicate that climatic variables may be the primary control on stream temperature.</td></tr>
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Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Loizeau, Jean-Luc and Janusz Dominik. 2000. Evolution of the Upper Rhone River discharge and suspended sediment load during the last 80 years and some implications for Lake Geneva. Aquatic Sciences 62: 54-67.	2000	Sediment Loading	Peer reviewed Basic Research	Rhone River, Switzerland	temperate		hydroelectric		Sediment rating curve, sediment load, dam, deep water lake.
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Loizeau and Dominik (2000) study the sediment loading into a reservoir due to increased regulation on upstream tributaries of the Rhone River. Sediment loading into Lake Geneva was identified through analysis of developed sediment rating curves. Results indicated that sediment input into the reservoir has reduced by at least a factor of 2. This reduction in sediment load, in part due to the reduction of floods from upstream regulation, raises concerns about a reduced underflow on the lake bottom and corresponding reoxygenation of deep waters.									
Lytle, D.A. and D.M. Merritt. 2004. Hydrologic regimes and riparian forests: a structured population model for cottonwood. Ecology 85(9): 2493-2503	2004	Cottonwood establishment and survival	Peer Reviewed Basis Research	Yampa River, CO	Arid		Free Flowing		Cottonwood, crowding dependence, density dependence, disturbance, drought, flooding, hydrologic alteration, natural flow regime, *Populus*, self-thinning, stochastic model.
Lytle and Merritt (2004) developed a stochastic, density dependent, population model to describe how annual variations in the hydrograph affect cottonwood mortality and recruitment. Using vital rates for cottonwood – birth and death rates – results observed complex population dynamics from these fundamental quantities. Findings showed a cycle of high flood mortalities in seedlings, but a more consistent periodicity of 5-15 years of adult cottonwood (*Populus deltoides*) driven by multiyear sequences of flows favorable to stand recruitment (>2 years). The multiyear sequences with specific hydrologic characteristics for juvenile success were shown to be more important than single-year events. Furthermore, drought years gave rise to establishment by competing plant species via elimination of up to 50% of available cottonwood habitat, which established a quasi-equilibrium model for population size. The effects of vital rates linkages to hydrology within the model demonstrate hydrology as the “master variable” in floodplain forest development. Regarding flow regimes, the developed model showed high flood frequency resulted in stable population sizes, while stabilized flow regimes resulted in highly variable population sizes prone to local extinction.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Mahoney, J.M. and S.B. Rood. 1992. Response of a hybrid poplar to water table decline in different substrates. Forest Ecology and Management 54: 141-156.	1992	Cottonwood seedling recruitment	Peer Reviewed Basic Research	Lab					Cottonwood, poplar, water table decline, substrate
Mahoney and Rood (1992) investigated the effects of the rate of water table decline along with substrate texture on growth and transpiration of *Populus balsamifera* x *P. deltoides* hybrid clones. Water table declines of 1, 2, 5, and 10 cm/day and gravel, sand, and mixed gravel/sand substrates were used. With a constant water table, clones grew best in gravel since sand grown plants experienced anaerobic conditions. However, with increasing rates of water table decline, plant shoot growth was decreased. This effect was most extreme in gravel substrates, then mixed, and lastly in sand since finer textured substrates were more able to hold water higher above the water table level: 5 cm above in gravel, 50cm in mixed, and 70cm in sand. However, at intermediate rates of decline, root elongation was promoted, especially in sand. The longest roots were observed in sand grown plants with a water table decline of 10cm/day. Transpiration decreased in gravel grown plants with an increase in water table decline, but increased in sand grown plants, since sand grown plants were able to maintain contact with the water surface. Overall, this study shows the importance of both rate of water table decline and substrate type on the growth of *Populus* clones, this is important for future development of regulated flows that can be survived by Poplars downstream of dams.									
Mahoney, J.M. and S.B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. Wetlands 18(4): 634-645.	1998	Cottonwood seedling recruitment	Literature review and synthesis	Western U.S.	semiarid				cottonwoods, hydrology, modeling, Populus, riparian zone, seedlings
Mahoney and Rood (1998) present a recruitment box model for cottonwood species. The “box” is a zone in elevation and time where seedlings are likely to establish if ideal hydrologic conditions are met. In general moderate flood events from a 1 in 5 to a 1 in 10 year flood provide the ideal amount of erosion and water flows/levels for recruitment. Seed release occurs slightly after peak stream flows and seedlings are likely successfully recruited if deposited 60-150 cm above base stream flow. Although first year seedling roots usually grow to only 60 cm they can persist via usage of the capillary fringe, an aerobic zone of moisture wicked up above the riparian water table. In fine textured soils, especially on larger rivers, this permits the seedling recruitment band to extent up to 200 cm. Stream stage decreases after peak flows, initially very rapidly, and the authors determined that a maximal stage decrease of 2.5 cm per day is survivable, depending on site specific conditions. The authors described how an understanding of the box model and cottonwood seedling hydrological and physiological requirements can be used in development of flow prescriptions on dammed rivers.									
Mallik, A.M. and J.S. Richardson. 2009. Riparian vegetation change in upstream and downstream reaches of three temperate rivers for hydroelectric generation in British Columbia, Canada. Ecological Engineering 35(5): 810-819.	2009	Dam effects on vegetation	Peer Reviewed Basis Research	Allouette, Coquitlam, and Cheakamus Rivers, British Columbia	Temperate	200, 193, 771 sq km respectively	Hydroelectric		Hydroelectric dams and reservoirs, Riparian plants, Ordination, Species richness, Species diversity Mosses, Red alder Western red cedar
Mallik and Richardson (2009) studied upstream and downstream reaches of three British Columbia Hydro reservoirs to determine if the dams affected riparian plant communities. For the individual rivers there was marked difference between upstream and downstream species abundance, richness, and diversity, however there was larger difference amongst the three similar rivers. Due to this, one could argue that in this region dam management is within the natural flow regime. The one significant caveat is there were significant reductions in red alder (*Alnus rubra*) and western red cedar (*Thuja plicata*) downstream of the reservoirs. This finding is attributed to a reduction in peak flow events and the lack of sediment transport due to reservoirs, and proper mitigation procedures could use the Recruitment Box Model to plan releases.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Meier, C.I. 2008. Cottonwood establishment in a gravel-bed river. Dissertation. University of Montana, Missoula, MT.	2008	Cottonwood Establishment	Dissertation	Flathead River, Montana, USA	Semi-Arid	2920 sq km	Free Flowing	8 - 9 km	cottonwood, substrate

Meier (2008) discusses the nature of cottonwood germination in gravel-bedded streams. He puts forth a new hypothesis involving submerged germination, with the germinant establishing during the early parts of the receding hydrograph – this is similar to our hypothesis, and functionally the same, but involves submerged germination instead of germination on the floodplain. Field and laboratory studies corroborate this hypothesis with settling rate studies, fluvial transport studies, and submerged germination studies. Much of the rest of the article is information that is functionally similar to our models, however the refutation of the recruitment box model requires a counter argument to the groundwater interactions, which is presented in the fifth chapter. A laboratory study is done using coarse material to cover wetted finer substrates and assess water loss. The coarse cover was 8 or 4 cm compared to bare fine substrate, and at the conclusion of the experiment there was 5.3 and 3.7 times more water present, respectively, compared to bare substrate – a demonstration that cottonwoods may not be obligate phreatophytes, and conditions of a gravel-bedded river could allow for cottonwood establishment without groundwater interactions.

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Merritt, D.M. and D.J. Cooper. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River Basin, USA. Regulated Rivers: Research & Management 16:543-564.	2000	Riparian Response to Flow Alteration	Peer Reviewed Basis Research	Green River, USA	Arid		Free Flowing and Regulated		channel change; channel geometry; fluvial marsh; Green River; metamorphosis; regulated river; riparian vegetation; Yampa River

Merritt and Cooper (2000) study the hydrologic and riparian processes of two historically similar stream reaches through the development and subsequent flow regulation of one, while the other remained with its natural flow regime. The rivers were both historically at a quasi-equilibrium as meandering channels, however following flow regulation the regulated river is trending towards a new state, while the natural flow regime has maintained historical function and process. The regulated reach has undergone a complex series of morphological changes through three stages, (1) dam closure lead to channel narrowing and vegetation encroachment of salt-cedar, (2) the toe slopes have begun to erode contributing bedload that has created emergent bars and fluvial marshes, and (3) the bank continues to erode, leading to an island growth phase. During these phases the riparian forest has senesced and lost the poplar forests to a desert shrubland.

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Merritt, D.M. and N.L. Poff. 2010. Shifting dominance of riparian Populus and Tamarix along gradients of flow alteration in western North American Rivers. Ecological Applications 20(1): 135-152.	2010	Riparian Response to Flow Alteration	Peer Reviewed Basis Research	13 Streams in the Western United States	Arid and Semi-Arid		Unregulated and Regulated - Hydro, Agricultures, Flood		dams; flow management; flow regime; index of flow modification; invasive species; Populus; river management; river restoration; tamarisk; Tamarix ramosissima; vegetation change; water development.
Merritt and Poff (2010) tested the hypothesis that *Tamarix* distribution and success over native species is a result of modified flow-regimes. Biologically relevant attributes of flow alteration were quantified for native and non-native riparian plant species, and then abundance and recruitment were compared between sites (8 ecoregions, 13 rivers, and 54 sites). Hypotheses were tested for the recruitment, abundance, and dominance for *Tamarix* and *Populus* related to a dimensionless number relating the index of flow modification pre- and post-damming. Results show even a slight modification of the flow regime dramatically reduces the probability of *Populus* recruitment and dominance, however the reduction has more to do with a modified flow regime than the presence of *Tamarix*. *Tamarix* has been found to have better recruitment along less regulated streams and then across a gradient of regulated flows, demonstrating that the modified flow-regime does not assist the *Tamarix* in recruitment and survival. *Tamarix* is however more suitable for the new bottomland conditions resulting from a modified flow regime, and thus it is seen to be dominant along modified streams where the modification has left unsuitable conditions for *Populus* to recruit and establish.									
Merritt, D.M., M.L. Scott, N.L. Poff, G.T. Auble, and D.A. Lytle. 2010. Theory, methods and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds. Freshwater Biology 55(1): 206–225.	2010	riparian vegetation-flow response guilds	Literature review and synthesis	Mid-west, Western US, Canada	Semi-arid, Temperate	varies	Multiple	varies	environmental flows, hydrologic alteration, plant water relations, riparian vegetation, vegetation models
Merritt et al. (2010) develop a predictive framework for modeling riparian vegetation - stream flow relations using riparian vegetation-flow response guilds, which are non-phylogenetic groupings of species with similar traits in life history, reproductive strategy, morphology and disturbance response. The authors review existing models that quantitatively relate components of the flow regime to attributes of riparian vegetation at the individual, population and community levels. They describe strengths and weaknesses of existing models and outline how many of the existing models are not readily transferable to different species or systems as they are typically tailored to a given system, river, reach or segment and a subset of focal species. The authors present strategies to define riparian response guilds and provide a framework for translating patterns between river systems to predict vegetation response to projected changes in flow regime. They summarize attributes of riparian vegetation and their sensitivity to hydrologic alteration at different time scales. Species response curves to disturbance and environmental limitations and probabilistic models of species distributions along quantified gradients of water availability and fluvial disturbance are needed to define riparian response guilds.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Milhous, R.T., I.G. Jowett, T.R. Payne, and J.M.D. Hernandez. 2012. Modeling environmental flow needs for riparian vegetation. AWRA 2012 Summer Specialty Conference. Denver, Colorado, June 27-29, 2012.	2012	Environmental Flows and Riparian Vegetation - Computer Model	Conference Paper						environmental flow analysis, modeling, riparian vegetation analysis
Milhous et al. (2012) developed a System for Environmental Flow Analysis (SEFA), which is a computer model with the capacity to produce 1) a relationship between flow and stage along a river, 2) determine the area inundated, and 3) determine the number of days inundated by season and year, all for riparian areas. SEFA is an improved replacement of the Instream Flow Incremental Method (IFIM), further including sediment analysis (flushing flow and deposition), water temperature, dissolved oxygen, and a time series analysis and modeling of streamflow needs for riparian areas. SEFA can model dimensionless shear, and be used to determine required flow for vegetation removal. For seedling establishment, two indices have been established, 1) an index based on peak daily discharge, and 2) an index based on the width of the cross section. The model is further being developed to model riverbed conditions required for seedling establishment and recruitment, and model scour for the removal of unwanted vegetation.									
Molnar, P., M.V. Birsan, V. Favre, P. Perona, P. Burlando, and C. Randin. 2008. Floodplain forest dynamics in a hydrologically altered mountain river. Peckiana 5: 17-24.	2008	Dam effects on vegetation	Dissertation	Maggia River, Switzerland	Temperate		Dammed	58 km	dam effects, groundwater
Molnar et al. (2008) use an aerial photography approach to look at downstream effects of damming. With the most affected flows in the summer rather than the flood peaks, moderating summertime flows led to an increase in riparian vegetation cover, a decrease in exposed sediment and grass/shrub cover, and a loss of natural vegetation dynamics. The crucial components lost in the damming were the timing and magnitude of floodplain inundation, and a general drop in groundwater levels. This was due to small reservoir size not being able to control flood pulses, allowing floods to pass, however the magnitude and timing of mid-summer flows was reduced ~75%. These changes altered the recruitment and establishment of riparian vegetation. The nature of aerial photography was a limiting factor in identifying intra- and inter-annual riparian vegetation variability, and limits the conclusive connections between vegetation growth and hydrology.									
Moore, J.N. and E.M. Landrigan. 1999. Mobilization of metal-contaminated sediment by ice-jam floods. Environmental Geology 37: 96-101.	1999	Reservoir-stored sediment mobilization due to ice-jam flooding	Peer reviewed Basic Research	Clark Fork River, Montana	Temperate		other		metals, sediment, contamination, ice jam, floods
Moore and Landrigan (1999) evaluate metal concentrations in sediment downstream of the Milltown Dam on the Clark Fork River due to mobilization of metal-contaminated sediments from a flood induced by a large ice-jam within the reservoir. The study found that metal concentrations within sediment decreased in the reaches upstream of the reservoir and were likely due to dilution of contaminated sediment from scoured, uncontaminated bank sediment. In these reaches, ice-jam flooding eroded into floodplain deposits and up to 2 meter eroded banks were common along large portions of the open reaches. Lowering of stage within the reservoir prior to the ice jam flood to protect the dam exposed large amounts of sediment and flows appeared to have eroded banks up to 1 to 2 meters high and mobilized slumps within the reservoir up to 10 meters long. At the corresponding high stages of the flood event, the sediment was found to have transported over the dam and deposited downstream. This study found ice-jam events to have the capacity to mobilize large amounts of sediment.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Mortenson, S.G. and P.J. Weisberg. 2010. Does river regulation increase the dominance of invasive woody species in riparian landscapes? Global Ecology and Biogeography 19: 562-574.	2010	Riparian vegetation response to flow alteration	Peer Reviewed Basic Research	Southwestern United States	Semi-arid		Free-flowing to heavily regulated	20 river segments on 14 rivers	Dams, *Elaeagnus*, flow regimes, hydrology, invasions, *Populus*, riparian vegetation, *Salix*, south-western USA, *Tamarix*
Mortenson and Weisburg (2010) evaluated how dams in the southwestern US changed hydrological parameters and how these affect the dominance of native and non-native woody taxa: *Populus, Salix, Tamarix*, and *Elaeagnus*. Several indicators of hydraulic alteration were analyzed including constancy (variation in daily flow magnitude) and contingency (variation in timing of flows of similar magnitude among years), as well as other factors including drainage area and climate. In dammed rivers versus undammed rivers the number of high pulses, constancy, August flows, minimum flows, base flow, date of max flow, and recession rate increased, contingency and max flow rate decreased, and high pulse duration, mean annual flow, timing of minimum flow, and May median flow remained unchanged. Non-native plant cover was best explained by the additive effects of constancy and drainage area. *Tamarix* in particular, increased in dominance with increasing regulation up to the highest levels of dominance at moderate levels of flow regulation. *Populus* dominance was affected by maximum July temperatures and the number of high pulses, in river segments with a high maximum temperature, *Populus* showed low dominance unless there were frequent high pulses. *Populus* cover was negatively related to flow regulation. Overall, the trends observed for *Populus* showed that its response is driven by water availability. *Salix* and *Elaeagnus* were unrelated to the level of flow regulation, likely due to clonal growth and animal dispersed seed, respectively, decoupling their reproduction from flow. This research shows that the native vs. non-native respective decrease and increase of dominance due to flow regulation is unsubstantiated, and the importance lies in species specific life history strategies for determining species response to flow.									
Mouw, J.E.B, J.A. Stanford, and P.B. Alaback. 2009. Influences of flooding and hyporheic exchange on floodplain plant richness and productivity. River Research and Applications 25: 929-945.	2009	Floodplain species richness	Peer reviewed basic research	Middle Flathead River, Montana and Talkeetna River, Alaska	Temperate and Boreal		unregulated	Middle Flathead: 148 km, Talkeetna: 137 km	flood plain; river; vascular plants; species richness; productivity; flooding; disturbance; ground- and surfacewater interactions; hyporheic
Mouw et al. (2009) evaluated the correlations between plant species richness and several factors on floodplains along two unregulated rivers in Montana and Alaska. Factors evaluated included: sediment particle size, flood duration, cover of large woody debris, substratum heterogeneity, and the vertical hydraulic gradient (or ground water/surface water interactions). They found that along both rivers, species richness was highest along depositional plains and poorest in scour zones. At the plot level, richness was highest in areas with small sediment particle size and with groundwater upwelling. Along the Middle Flathead River, the presence of large woody debris also increased species richness. Additionally, species richness was not related to the elevation of the floodplain of the frequency of flooding, but was influenced by the floodwater energy. Finally, plant growth in addition to species richness was also significantly higher in areas with groundwater upwelling along both rivers.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Mouw, J.E.B., J.L. Chaffin, D.C. Whited, F.R. Hauer, P.L. Matson, and J.A. Stanford. 2012. Recruitment and successional dynamics diversify the shifting habitat mosaic of an Alaskan floodplain. River Research and Applications 29: 671-685.	2012	Floodplain Succession	Peer Reviewed Basic Research	Kwethluk River, AK	Boreal		Free-flowing	27 km reach	recruitment; primary succession; shifting habitat mosaic; flooding; herbivory; secondary succession; Kwethluk River; Alaska
Mouw et al. (2012) investigated the primary and secondary succession pathways as related to the physical characteristics, herbivory, and beaver habitat engineering along the Kwethluk River, AK. They found strong evidence of channel migration, bar accretion, and succession for hundreds of meters laterally along the river and described the successional pathways they observed. On ridges, as the channel migrated laterally, Salix and Alnus species colonized bars along the lateral margins and tails, regardless of elevation and depth of fine-grained sediment. Populus species were observed after 30 years and Picea glauca after 125 years. They also describe the variety of herbaceous species observed during each stage of succession. Within swales, succession was arrested and a tundra climax state occurred. The authors also discuss how herbivory and habitat engineering by beavers has lead to a secondary succession pathway resulting in wet meadow formation in approximately 12% of the 40km^2 area they investigated.									
Naito, A.T. and D.M. Cairns. 2011. Relationships between Arctic shrub dynamics and topographically derived hydrologic characteristics. Environmental Research Letters 6: 045506. Online. (stacks.iop.org/ERL/6/045506). Accessed 20 December 2013.	2011	Arctic Shrub Expansion	Peer Reviewed Basic Research	Brooks Range and North Slope Uplands, Alaska			free flowing		shrub expansion, riparian vegetation, hydrology, topographic wetness index, Arctic, Alaska
Naito and Cairns (2011) revisited the work of Tape et al. (2006) to describe shrub expansion in the Brooks Range and North Slope Uplands of Alaska and relate expansion to local hydrologic conditions. Tape et al. (2006) showed shrub expansion to be a principal part of Arctic change with the largest increases occurring on floodplains and valley slopes. Shrubs are thought to be expanding in the Arctic due to warming which increases productivity, and increased soil nutrient production as a result of increased snowpack around shrubs. The authors found increased shrub cover of 3.38 - 76.22% at floodplains they investigated. Areas with increased shrub cover were positively related to decreased distance to the river bank and also areas with higher topographic wetness index (TWI) values. Therefore, shrubs expanded into areas where the river channel had migrated over time and also into areas with greater moisture accumulation potential. The future of shrub expansion and survival is undetermined. Climate warming is predicted to increase shrub survivorship. However, due to an overall decrease in sediment input since two Pleistocene-Holocene transition mass-wasting events, shrubs in floodplains could continue to stabilize river bank sediments and decrease channel migration in the future.									

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<tr><th>Citation</th><th>Year</th><th>Topic</th><th>Source Type</th><th>Location</th><th>Habitat Type</th><th>Watershed Size</th><th>Hydrologic Regime</th><th>River Length</th><th>Key words</th></tr>
<tr><td>Nanson, G.C. and J.C. Croke. 1992. A genetic classification of floodplains. Geomorphology 4(6): 459-486.</td><td>1992</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>floodplain classification</td></tr>
<tr><td colspan="10">Nanson and Croke (1992) review observations of the formation of floodplains including depositional and erosional processes, review existing floodplain classifications, and propose a new genetic floodplain classification. Riparian vegetation is not included in their analysis. The genetic classification system is proposed to draw out importance of the interrelation between river processes and the floodplains they construct. They present alternate floodplain definitions including hydraulic floodplain and genetic floodplain. In this classification, stream power (the stream's ability to entrain and transport sediment) and sediment character (erosional resistance of floodplain alluvium at the channel boundary) define floodplain character and evolution. Orders and suborders are recognized according to channel confinement and grain size or sediment texture. Block diagrams illustrate floodplain classes and orders. They propose that substantial environmental change will result in predictable transformation from one floodplain type to another because floodplains are derivatives of the parent stream system.</td></tr>
<tr><td>Natural Resources Conservation Service. 2004. Land resource regions and major land resource areas of Alaska. United States Department of Agriculture.</td><td>2004</td><td>Ecoregions</td><td>White Paper Report</td><td>Alaska</td><td></td><td></td><td></td><td></td><td>None</td></tr>
<tr><td colspan="10">NRCS (2004) delineated and described the five land resource regions (LRR) in Alaska: Southern AK, Aleutian AK, Interior AK, Western AK, and Northern AK. These are areas delineated based on regional climate and climatic conditions, processes and patterns. Within these regions they determined 27 major land resource areas (MLRA). These are areas delineated by physiographic, geomorphic patterns and processes, and general vegetation potential. Within each MLRA specific physiography, geology, climate, soils, biological resources, and land use were described.</td></tr>
<tr><td>Nilsson, C. and M. Svedmark. 2002. Basic principles and ecological consequences of changing water regimes: riparian plant communities. Environmental Management 30(4): 468-480.</td><td>2002</td><td>Dam effects on riparian vegetation</td><td>Literature review</td><td></td><td></td><td></td><td></td><td></td><td>Flow regime; Land–water interactions; Management; Plant communities; Riparian corridor; River</td></tr>
<tr><td colspan="10">Nilsson and Svedmark (2002) reviewed research on dams and riparian communities to determine the three basic principles of riparian systems that are affected by dams and that must be addressed during management of river systems and possible restoration. Riparian zones are unique ecosystems without equilibrium that interact in four dimensions: longitudinally along their course, laterally with the floodplain, vertically with the soil and groundwater environment, and temporally. The first principle of riparian systems is that flow regime drives changes in riparian plant communities and ecological processes. Variable flows influence riparian systems on different scales, from changing large geomorphic traits down to plant species community composition. Secondly, the riparian corridor permits movement of sediments, nutrients, plant seeds/propagules longitudinally and laterally. This redistribution of materials impacts plant community structure, composition, and health. Lastly, riparian areas serve as a boundary, interface, ecotone, and transition zone all in one and are thus more species rich than other surrounding ecosystems. Meandering rivers have the highest biodiversity and in free flowing rivers the middle reaches have been found to be the most species rich. In order to manage rivers and riparian systems these three principles need to be understood as well as the importance of the different spatial dimensions and timescales. Finally, the authors cite case studies to show that in order to maintain the functioning of these three principles in riparian systems it is best to attempt to restore flow to natural conditions to ensure dispersal of seeds/propagules, nutrients, and sediments and reconnect the riparian zone with the surrounding environment.</td></tr>
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Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Nilsson, C. and K. Berggren. 2000. Alterations of riparian ecosystems caused by river regulation. Bioscience 50(9): 783-792.	2000	Riparian Response to Flow Alteration	Peer Reviewed, Literature Review						None
Nilsson and Berggren (2000) detail upstream and downstream effects of river regulation, and then discuss future needs and directions. Upstream effects entail the inundation of habitats and resultant new riparian zones. In the inundation process, if trees aren't harvested, the decomposition of the old forest creates greenhouse gases and methylmercury which bioaccumulates. Additionally, the increased nutrient levels from the decomposition can lead to introduced species that can foul waterways, taint potable water, usurp reservoir volume, etc. The new riparian habitat of a reservoir doesn't possess the same characteristics of the preflooded habitat. Downstream effects include hydrologic and geomorphic effects, riparian community succession, salinization, and invasive species introduction. The first two effects are well documented elsewhere. Salinization is a process occurring when the floodplain doesn't receive enough floodwaters to recharge the saline soils and groundwater depleted during ET. Invasion of exotic species occur due to the lost disturbance and altered environmental conditions of a regulated river. A last note of anecdotal interest: there is approximately 10,000 km^3 of water stored in reservoirs, that's equal to five times the volume of water in all the rivers of the world, or 10 cm water depth across all the land surfaces of the world.									
Nilsson, C. and R. Jansson. 1997. Long-term responses of river-margin vegetation to water-level regulation. Science 276: 798-800.	1997	Regulation effects on vegetation	Peer reviewed Basic Research		Boreal		reservoir and run-of-river		dam effects, flow regulation, plant community
Nilsson and Jansson (1997) evaluated the effect of flow-regulation on riparian vegetation in central and Northern Sweden. River-margin vegetation was studied at over 40 sites each on reaches downstream of storage reservoirs and run-of-river impoundments ranging between 1 and 70 years. Presence of vascular plant species, percent cover of trees and shrubs, percent cover of herbs and dwarf shrubs, height of river-margin, substrate fineness, and substrate heterogeneity were recorded. River-margin downstream of storage reservoirs was found to have fewer plant species and reduced species richness (i.e., concentration) compared to free-flowing rivers. River-margin downstream of run-of-river impoundments was found to have fewer plant species but the same species richness as that of free-flowing rivers. Management methods to maintain species richness on regulated rivers, such as developing a system that offsets seasonal fluctuations in flow, are suggested.									
North, Margaret E A, and Michael Church. Studies of Riparian Vegetation along Peace River, British Columbia. In The regulation of Peace River. ms. Edited by Michael Church. In preparation.	In preparati on	Dam effects on vegetation	Chapter in Book	Peace River, British Columbia and Alberta	Boreal		hydroelectric		regulated river, riparian succession, riparian vegetation, vegetation classification
North and Church (In preparation) conduct an analysis of riparian vegetation along the Peace River in order to determine changes in vegetation due to river regulation in the late 1960s. From data collected by 4 field visits over 17 years in combination with 6 aerial photography sets between 1953 and 1996, relationships between the hydrologic, geomorphologic and riparian vegetation were established. A vegetation succession model for natural flow conditions was developed in order to determine natural successional changes versus changes caused by flow regulation. Prior to application on the post-regulation Peace River, the vegetation successional model was tested on a series of aerial photographs from the 1950s. Conclusions of the study include an observed lower floodplain (previously at the former bar-top level), ice-induced flooding that continues to retard vegetation establishment of shrub communities, higher winter flows due to regulation that have appeared to damage establishment of vegetation during summer due to persistent winter inundation, and reduced fertility of old floodplain soils from decreased higher flooding coupled with a lowered floodplain water table that has resulted in an earlier mortality of cottonwood stands.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Papa, F.C. Prigent and W.B. Rossow. 2007. Ob' River flood inundations from satellite observations: A relationship with winter snow parameters and river runoff. Journal of Geophysical Research 112: D18103.	2007	Hydrology	Peer reviewed Basic Research	Ob River Watershed in Siberia	Boreal				None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Papa, Prigent and Rossow (2007) examine the spatial and temporal variations of monthly inundation extents of the boreal Ob River basin through satellite and in-situ data collection. Results indicated a strong correlation between inundation extent and snowmelt parameters in the southern (more upstream) region of the watershed. In the northern (more downstream) region of the watershed, inundation (i.e., flooding) correlated more strongly to the amount of contributing water from the upper watershed. The study identifies the methods used as an adequate way to determine seasonal and interannual variations of inundation in a large watershed that exhibits a snow-inundation-runoff relationship.									
Payne, T.R. and I.G. Jowett. 2013. SEFA - computer software system for environmental flow analysis based on the instream flow incremental methodology. Proceedings of the 2013 Georgia Water Resources Conference. Athens, Georgia, April 10-11, 2013.	2013	SEFA - Software for instream flow analysis	White Paper						Water resources management, riverine habitat modeling, environmental flow analysis, physical habitat simulation software, instream flow evaluation
Payne and Jowett (2013) developed a software framework SEFA (System for Environmental Flow Analysis) that implements the substance of IFIM (Instream Flow Incremental Methodology) and goes beyond the basic minimum flow needs. The model includes several additional features such as hydrologic analysis, hydraulic and habitat modeling, water temperature modeling, habitat selectivity criteria development, sediment scour, transport, and deposition analysis, riparian habitat evaluation, and hydrologic and habitat time series analysis – the model has the capacity to complete sophisticated hydraulic assessments to study effects upon riparian habitat. The model is one-dimensional, but two-dimensional model results can be input into the model, thus riparian vegetation inundation can be modeled with SEFA for frequency, timing and duration. The model is developed to model fish habitat, and the riparian component is small, and only concerns inundation.									
Peters, Daniel L. and Terry D. Prowse. 2001. Regulation effects on the lower Peace River, Canada. Hydrological Processes 15: 3181-3194.	2001	Flow regulation effects on downstream hydrographs	Peer reviewed Basic Research	Peace River, Canada	Boreal		hydroelectric		flow regulation, hydraulic flood routing, annual peak flow
Peters and Prowse (2001) evaluate the effects of flow regulation on downstream hydrographs on the Peace River, Canada. The river was initially altered in 1968 by the construction of a hydroelectric dam. In this study, a naturalized flow regime (i.e., a regime without regulation effects) during the period of 1972-1996 was developed with hydrologic and hydraulic flow models and compared to the flow regime from observed regulated effects during the same period. The comparison showed that large differences in the hydrograph were observed as much as 1100 km downstream. Annual winter flows were significantly increased under the post-regulation hydrograph, annual peaks (daily, bi-monthly, and monthly) were reduced and daily flow variability decreased. Overall, the post-regulation downstream hydrograph maintained the same trend as the pre-regulation hydrograph. Tributary inflow to the Peace River downstream of the dam was found to be the factor in maintaining a pre-regulation hydrograph trend.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Petts, G.E. 2009. Instream-flow science for sustainable river management. Journal of the American Water Resources Association 45: 1071-1086.	2009	Instream flow science	White Paper Report						None
Petts (2009) states that a turning point has been reached in instream flow science where we recognize the importance of conservation of riparian ecosystems and allocating water for environmental needs, this concept is termed "e-flows". Petts discusses the history of riverine ecosystem and water resources management and introduces critical tools used to evaluate habitat and manage river flows in the past such as the Instream Flow Incremental Methodology (IFIM) and Physical Habitat Simulation (PHABISM), as well as a variety of hydrological, habitat, and science-informed panel assessment approaches. Case studies of differing methodologies are presented. The author provides a framework for future e-flow science, stating that biological and physical processes need to be investigated alongside each other and climatic and geomorphological cycles as well as biological dynamics must be incorporated into future models.									
Poff, N.L., J.D. Allen, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime. BioScience 47(11): 769-784.	1997	Natural Flow Regimes	Literature Review and Synthesis						flow regulation
Poff et al. (1997) reviews and synthesizes literature regarding the role of natural flow regimes for riverine health. Due to loss of species, groundwater depletion, declines in water quality and availability, and more frequent intense flooding increased attention has been brought to the restoration of rivers – though there is still failed recognition to the natural flow regimes for restoration. Natural flow restores critical physical characteristics such as temperature, geomorphology, and habitat. Poff et al. cites five major components of the flow regime, 1) magnitude of discharge, 2) frequency of occurrence, 3) duration of flow, 4) timing, and 5) rate of change, which all define and organize rivers that have evolved to these components. Allowance of these variances facilitates healthy riverine systems through rejuvenation and perpetuated connectivity of aquatic and terrestrial systems that give rise to healthy flora and fauna, otherwise under stabilized conditions the river could destabilize from its natural state and invasive species could flourish. Recent approaches to streamflow management have focused on singular species and minimum flows (e.g., the IFIM model), but it's suggested a broadened species focus and the need for variable streamflow would facilitate greater ability for true restoration. This paper also includes effective figures and tables for instructing principles of natural flow regimes.									
Polzin, M.L. and S.B. Rood. 2000. Effects of damming and flow stabilization on riparian process and black cottonwood along the Kootenay River. Rivers 7(3): 221-232.	2000	Dam effects on vegetation	Peer Reviewed Basis Research	Kootenay River; Montana and Southern BC	Semi-Arid		Hydroelectric and Flood Control	200 km	Cottonwood seedlings, floodplain ecology, fluvial geomorphology, instream flow needs
Polzin and Rood (2000) use a comparative study of a river above and below a dam, and an adjacent drainage, to look at downstream effects on riparian process and cottonwoods (*Populus* spp.) for dammed rivers in semi-arid regions. Hydrologic, geomorphic, and ecological changes were investigated assessing relations between instream flow patterns, channel process, and riparian shrubs and tree survival. This was done using stream discharge, aerial photography, surface substrate composition, and riparian transects assessing seedling establishment, and species abundance. The presence and management of the dam have affected discharge and sediment transport resulting in 1) reduced channel movement, 2) depletion of fine sediment, 3) scarcity of woody debris, and 4) the encroachment of upland vegetation into the recruitment band of the riparian zone. These effects have combined and eliminated seedling establishment of cottonwood and willow. As well as drastically reduced understory shrubs and increased grasses – increasing competition for seedling establishment. While deciduous shrubs and trees are not recruiting a progressive shift in community to coniferous trees is occurring.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Power, M.E., W.E. Dietrich, and J.C. Finlay. 1996. Dams and downstream aquatic biodiversity: potential food web consequences of hydrologic and geomorphic change. Environmental Management 20(6): 887-895.	1996	Dams and Food webs	Literature review						Dams; Food webs; Hydrologic disturbance; Predator-prey dynamics; Succession
Power et al. (1996) reviewed case studies and presented a model for how alteration of flow regimes impacts predator-prey interactions in food webs. Often food chain length is an indicator of a more pristine ecosystem or one with greater biodiversity. Flow variation can affect food chain length in multiple ways. Predator-prey dynamics can be disrupted when flows change the geomorphic structure of a stream in ways that destroy this balance. Flooding of floodplains links the terrestrial habitat with the aquatic and can provide feeding areas, nurseries or overwintering habitat for aquatic biota. If floods are decreased in magnitude or frequency this reduces access to the floodplain and can remove these linkages in the food chain and reduce productivity and viability of river species. Additionally, scouring during flooding provides a periodic change back to early successional stages of primary consumers or primary producers which can usually be easily predated upon. Reduced scouring stops this and therefore decreases energy transfer from lower to high food chain levels. Lastly, scouring can suppress invasive species along rivers when floods occur to wipe them out periodically. If flows are reduced vegetation (both native and invasive) may encroach into river channels and reduce flood conveyance as well as habitat for certain river species. The authors provided geomorphic, ecological, and socioeconomic considerations for pre-dam research and design. They state that a "hydraulic food chain model" incorporating geomorphic factors followed by creation and analysis of an interaction web to get at crucial ecological processes would be an effective approach to creating an adaptive management plan for regulated rivers, although management imitating a natural state would be most beneficial to biodiversity.									
Prowse, T D, S. Beltaos, J.T. Gardner, J.J. Gibson, R.J. Granger, R. Leconte, D.L. Peters, A. Pietroniro, L. Romolo, B. Toth. 2006. Climate change, flow regulation and land-use effects on the hydrology of the Peace-Athabasca-Slave System; findings from the Northern Rivers Ecosystem Initiative. Environmental Monitoring and Assessment 113: 167-197.	2006	Impact climate change, flow regulation, and land-use changes on hydrology	Peer reviewed Basic Research	Peace River	Boreal		hydroelectric		climate change, delta, floods, flow regulation, ice jam, land-use changes, northern rivers, synoptic climatology, water balance
As part of the Northern Rivers Ecosystem Initiative (NREI), Prowse et al. (2006) summarized results from a series of studies on the Peace-Athabasca-Slave river and lake system. Many studies on this river and lake system have been conducted however this study compilation, derived from the Northern Rivers Basin Study (NRBS), is focused on identifying potential hydrologic changes due to climate change, flow regulation and land-use changes. Topics include changes to aquatic perched basins on the Peace-Athabasca Delta based on historical and future climatic scenarios, frequency, magnitude and sources of major floods, specific hydrologic and climatic conditions to produce large ice-jam floods, and potential effect of climate and land-use changes on basin runoff and delta lakes. Some study results indicate that future climate scenarios suggest a quicker dry out period for the Peace-Athabasca Delta (thereby increasing the importance of inundation by overbank flooding), large overbank flooding events as the dominant factor in filling of higher elevation basins, and ice-jam floods are primarily developed from “trigger tributaries”.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Prowse, T.D. and F.M. Conly. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 2. Peace-Athabasca Delta. River Research and Applications 18: 447-460.	2002	Dam effect on river/lake delta	Peer reviewed Basic Research	Peace-Athabasca Delta on the Peace River	Boreal		hydroelectric		floods, river ice, ecosystem restoration, delta, flow regulation, climate variability
Prowse et al. (2002) study how the Peace-Athabasca Delta has been modified due to regulation upstream on the Peace River in 1968. The delta, located on the Lake Athabasca in Alberta, is formed by the Peace, Athabasca and Birch rivers and is the largest alluvial-wetland habitat in the region. Studies were initiated after the delta appeared to have continued drying and reduced ecologically significant habitat area. Through analysis of hydrometric data, open-water floods are not likely to result in overbank flooding. Ice jams however were observed to cause overbank flooding and inundation of secondary channels and basins even at discharges below typical summer open-water flows. The study found the decrease in frequency of large ice jams post regulation to be linked to flow-regime alteration and a reduced spring snowpack on tributaries downstream of the dam. While further studies are recommended, the primary observed effect of regulation was lowered winter ice levels. Through physical and numerical modeling studies of ice jams, strategies to increase ice-jam flooding were identified. One flow-augmentation strategy, identified by modeling and initiated in 1996, was found to produce high water levels resulting in overbank flooding and a recharging of the delta.									
Prowse, T.D., F.M. Conly, M. Church, and M.C. English. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 1. Peace and Slave rivers. River Research and Applications 18: 429-446.	2002	Flow regulation on geomorphology, ice-conditions, and riparian vegetation	Peer reviewed Basic Research	Peace and Slave River	Boreal		hydroelectric		floods; river ice; flow regulation; fluvial geomorphology; delta; riparian vegetation
Prowse et al. (2002) evaluated the impact of flow regulation on aquatic ecosystem controls on the Mackenzie, Peace and Slave rivers. The study was initiated in order to understand regulation effects on the hydrologic regime, ice-conditions, fluvial geomorphology and riparian vegetation in northern rivers where ice-induced floods appear to significantly affect controls of aquatic habitat. Changes in geomorphology were assessed through comparison of inter-decadal aerial photography. In reaches affected by a modified flow-regime (i.e., reaches closer to the point of regulation), the old floodplain was found to be shifting to a low terrace and vegetation was establishing on gravel bars. The active floodplain had declined in elevation however it remains unknown how long-term ice-induced flooding may affect this. Further all studied reaches showed channel narrowing between 4 to 16 % of pre-regulation channel widths due in part to the abandonment of some secondary channels. An altered flow regime of higher winter flows has modified the ice regime where ice cover has been lost in reaches immediately below the dam and delayed ice-cover further downstream. Regulation appeared to have not significantly modified the time or duration of the primary ice season at the most downstream end of Peace River. Changing ice-cover conditions has modified overbank flooding into riparian vegetation zones. A reduced flow-regime in the upper reaches has resulted in the reduction of mobile cobble and gravel bed-material and a corresponding stepped profile. On the Slave River Delta there has been a reduction in ecologically significant cleavage bars. It is unknown whether a general drying of some species on cleavage bars is a result of a reduced frequency in flood events. Large runoff events on the Peace and Slave rivers after the completion of this study have led to a follow-up study on the corresponding morphological effects.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Prowse, T., K. Alfredsen, S. Beltaos, B.R. Bonsal, W.B. Bowden, C.R. Duguay, A. Korhola, J. McNamara, W.F. Vincent, V. Vuglinsky, K.M. Walter-Anthony, and G.A. Weyhenmeyer. 2011. Effects of changes in arctic lake and river ice. AmBio 40: 63-74.	2011	Changes in River Ice	Peer Reviewed Basis Research	Arctic and Sub-Arctic					River ice, Lake ice, Climate, Arctic, Aquatic ecology, Northern development
Prowse et al. (2011) assesses the impacts of climate change on ice formation in river and lake systems. Forecasted changes include river ice break-up timing and severity which affect river geomorphology, vegetation, sediment and nutrient fluxes, and the sustainment of riparian-aquatic habitats. The effects of changes could be gradual or others abrupt as systems cross critical thresholds. Temperatures may reach levels at which there could occur mid-winter ice break-up that could have a significant effect on biological process. The altered timing and severity of break-up will alter flow regimes and thereby influence Arctic rivers as migratory routes, and the timing of fish runs and even larger mammals, such as caribou. There is little related to the alteration to riparian process in this article. The article also covers the effects of northern infrastructure, transportation, traditional lifestyles, and hydroelectric power.									
Prowse, T.D. and J.M. Culp. 2003. Ice breakup: a neglected factor in river ecology. Canadian Journal of Civil Engineering 30: 128-144.	2003	Ice Processes	Literature Review						river ice, river ecology, freshwater ecology, flooding, breakup, ice jam
Prowse and Culp (2003) reviewed and compiled information on the abiotic and biotic effects of ice breakup processes and related flooding on northern rivers. They lament the lack of inclusion of breakup processes in current ecological concepts such as the River Continuum Concept (RCC) and Flow Pulse Concept (FPC) and call for more research on ice processes so that the effects of breakup can be incorporated in these theories. Abiotic effects of breakup include river flows of large amplitude but relatively short duration. Floods during breakup are always greater than floods during open water conditions at an equivalent discharge. Breakup floods last on average 15 days dependent on river characteristics like size, steepness, and number of upstream tributaries. Breakup flows tend to carry a significant percentage of the annual sediment load, with peak sediment load occurring during breakup surges. Sediment erosion along banks and within the channel bed can occur and deposition commonly takes place at the head of islands and outer portion of river bends. Finally, water temperatures can rapidly increase during breakup causing rapid ice melt and an increase in discharge as well as a change in local microclimate. Biotic effects of breakup include scouring of vegetation along river banks, often resulting in the stepwise organization of vegetation by age class which can point to the severity and timing of past breakup events. Wetting and drying cycles caused by breakup floods permit riparian vegetation to occasionally persist in upland areas where it otherwise would not. Fauna such as aquatic invertebrates and fish can be temporary negatively affected by breakup, more severely when breakup occurs at unusual times coinciding with a fragile time in an organisms life cycle. Finally, water quality factors such as temperature, dissolved oxygen, organic matter, and sediment can all change rapidly during breakup, and these factors can either stimulate or impair primary production depending on timing and magnitude.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
R&M Consultants, Inc. 1981. Ice Observations 1980-1981. Anchorage, Alaska. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 Vol.	1981	Ice Processes	White Paper Report	Susitna	Boreal	50,764 sq km	Free-flowing	504 km	None
R&M Consultants (1981) was the first documentation of freeze up, winter, and breakup ice processes on the Susitna River as part of the 1980s hydroelectric project. Air temperatures were below normal in December and then unusually warm in January and precipitation was unusually low throughout the winter causing snowpack to be 40-70% of normal and ice thickness to be less this year. Historical freeze up and breakup data are spotty, but available from USGS gauging stations, the Alaska Railroad, and the National Weather Service. Freeze up in 1980 was slow, with the first observations of frazil ice on October 11, 1980. By December 30, 1980 ice cover extended four miles above Devil Creek with open water in turbulent reaches. Break up occurred between May 1-9 and several ice jams occurred, though the effects were relatively mild. Historical data showed frequent jams (almost annually) just below Curry and this year a jam also occurred just above Curry. Most of the ice scarring on trees occurred on vegetated islands at LRX-7.									
R&M Consultants, Inc. 1982. Ice Observations 1981-1982. Anchorage, Alaska. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 Vol.	1982	Ice Processes	White Paper Report	Susitna	Boreal	50,764 sq km	Free-flowing	504 km	None
R&M Consultants (1982) described ice observations and data from field work during the winter 1981-1982 season, continuing an ice study initiated in the winter of 1980-1981 on Susitna River ice processes. They presented detailed tables and graphs of climate, snow, and ice records from this time period compared to average and the previous winter. Overall freeze up occurred later and breakup was more dramatic with a lot of ice jamming and flooding during the winter of 1981-1982. The authors provided general observations on ice formation types and processes as well as breakup processes and then chronologically described each process during this winter. Freeze up occurred October 2, 1981 and breakup occurred from May 10-15, 1982. They also found that ice shelves at Devil Canyon this year were narrower and thinner than the previous year.									
R&M Consultants, Inc. 1984. 1982-1983 Susitna River Ice Study. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 472	1984	Ice Processes	White Paper Report	Susitna	Boreal	50,764 sq km	Free-flowing	504 km	None
R&M Consultants (1984) continued the work of describing Susitna River ice processes, this time from the winter of 1982-1983. The project was much more detailed this year than previously and directed towards specific problems that would be unique to the development of the Susitna hydroelectric project. The author gave detailed description of the freeze up process in addition to providing ice process terminology definitions. The Susitna was divided into 4 regions to describe ice formation. From the Cook Inlet to Chulitna confluence freeze up began October 22-26, 1982 and around October 12 from the Chulitna Confluence to Gold Creek zone. Above here ice formation was much more delayed and gradual. The break up process was then described in depth, with the main "drive" phase as the focus. The authors presented ideas about ice environmental effects such as how ice jams create and maintain sloughs, and move ice and sediment onto river banks, affect vegetation age and condition, and affect aquatic habitat. They hypothesized how ice processes and environmental effects would be modified with dam building.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
R&M Consultants, Inc. 1985a. Technical Memorandum: 1985 Susitna River Freeze-Up. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 3401.	1985	Ice Processes	White Paper Report	Susitna	Boreal	50,764 sq km	Free-flowing	504 km	None
R&M Consultants (1985a) provided a fifth year of data describing Susitna River ice processes only during freeze-up for the winter of 1984-1985. Chronological descriptions of observed ice formation were presented beginning with the first observation of slush ice formation on October 15. The winter of 1984-85 was a particularly cold winter with cold temperatures sustained throughout the duration of ice formation, thus permitting the process to advance very quickly compared to previous years. Tables detailing the location of the leading edge of ice and rate of ice advance in addition to detailed weather data (air temperature, weather description, water temperature, snowfall, etc.) are provided.									
R&M Consultants. 1985b. 1983-1984 Susitna River Ice Study. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 2743.	1985	Ice Processes	White Paper Report	Susitna	Boreal	50,764 sq km	Free-flowing	504 km	None
R&M Consultants (1985b) described in detail the freeze up and breakup processes on the lower Susitna River and briefly for the middle river for the winter 1983-1984. Average temperatures in the lower river in October were lower than normal but the number of accumulated freezing degree days were much fewer than normal, causing freeze up to take 40 days versus 14 days during the previous winter. This longer freeze up contributed to lower levels of staging and thinner ice. The tributaries contributing to the lower river were described in detail in terms of morphology, flow, and freeze up processes including the Chulitna and Talkeetna Rivers. The Yentna is a major contributor of ice to the lower Susitna River, contributing 50-60% of the ice in the lower river. Breakup in the lower river occurs gradually via candling while ice jams and ice cover persist in the middle and upper river, respectively. Historically, ice jams occur between river mile 77 and 96, but gradual melting contributes to little flooding. The flooding that does occur causes little erosion or damage to vegetation due to the broad floodplain along the lower river. Finally, the middle river freeze up and breakup were described briefly in order to continue computer simulations used to predict ice cover development with the intended dam in place. Once dammed, ice generation would be expected to be delayed, likely until into November, and higher flows under regulation would cause higher staging and increased ice thickness.									
Renofalt, B.M., D.M. Merritt, and C. Nilsson. 2007. Connecting variation in vegetation and stream flow: the role of geomorphic context in vegetation response to large floods along boreal rivers. Applied Ecology 44: 147-157.	2007	Plant Diversity and Flooding	Peer Reviewed Basis Research	Vindel River, Sweden	Boreal	12,654 sq km	Free Flowing	455 km	anaerobic, extreme floods, oxidation reduction potential, plant diversity, redox, resistance, riparian vegetation, river, tranquil reaches, turbulent reaches
Renöfält et al. (2007) studied the dynamics of riparian plant species composition and richness, and the importance of reach type in sustaining high species richness related to large and sustained floods in boreal forests. Results suggested that following flooding, reaches with slow-flowing water have species mortality and a reduction of richness, while in reaches comprised of rapids and runs, richness doesn't change. It is hypothesized the anaerobic conditions resulting from the finer grain sizes within the slow-flowing portions of the stream cause species stress and subsequent mortality; the rapids and runs maintain aerobic conditions through high groundwater turnover from a higher saturated conductivity. In the slow-flowing potions following floods, it was observed flood-intolerant species are prone to species loss and increased invasion by ruderal species, however recovery of species richness and composition occurs over time following the anaerobic conditions hypothesis.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Richter, B.D., J.V. Baumgartner, D.P. Braun, and J. Powell. 1998. A spatial assessment of hydrologic alteration within a river network. Regulated Rivers: Research & Management 14: 329-340.	1998	Flow Variation	Peer Reviewed Basis Research	Colorado River, US	Arid	761,343 sq km	Dammed		flow regulation, dam effects
Richter et al. (1998) used a 'range of variability approach' to assess the hydrologic alteration at available stream gauge sites throughout the Colorado River basin by mapping the degree of hydrologic variation at and between gauging sites. The 'range of variability approach' (RVA) is used to garner natural flow variation, and to assess the loss of hydrologic variation at the basin scale to facilitate river restoration planning – such as pre- and post-dam construction flow variability to restore a more natural flow regime. Parameters assessed in the model are: 1) magnitude of monthly discharge, 2) magnitude and duration of annual extreme discharge conditions, 3) timing of extreme discharge conditions, 4) frequency and duration of high/low flow pulses, and 5) rate/frequency of hydrograph changes. A hydrologic analysis was done on the entire river network to expand the long-term extent of data for the reach of interest.									
Rood, S.B. and S. Heinze-Milne. 1989. Abrupt downstream forest decline following river damming in Southern Alberta. Canadian Journal of Botany 67: 1744-1749.	1989	Cottonwood Forest Health Related to Hydro-regulation	Peer Reviewed Basic Research	St. Mary and Waterton, and Belly Rivers, Alberta, Canada			Regulated, and Free Flowing, respectively		cottonwood, dam effects
Rood and Heinze-Milne (1989) used aerial photography to assess the changes in abundance of cottonwood forests along two regulated and one unregulated reach in Southern Alberta. Results demonstrated three trends with respect to river damming and forest abundance, (1) forest decline occurred downstream of the dams, but not along the paired unregulated reach, (2) forest decline was greater downstream than upstream from the dams on the two regulated rivers, and (3) the duration of damming may play a role in the degree in forest decline. Downstream forest abundance changes for 20 years -47.8% (regulated 31 years), -22.9% (regulated 17 years), and -0.1 (unregulated).									
Rood, S.B., G.M. Samuelson, J.H. Braatne, C.R. Gourley, F.M.R. Hughes, and J.M. Mahoney. 2005. Managing river flows to restore floodplain forests. Frontiers in Ecology and the Environment 3(4): 193-201.	2005	River Restoration	Literature review and synthesis	Western North America					None
Rood et al. (2005) reviewed general impacts downstream of dams including hydrologic changes that adjust floods and in turn affect the physical processes of the river and its biota. Flow interruption by dams stops the movement of nutrients, sediment, organic matter and large woody debris, biota, and seeds, which can again have major effects on physical and biological processes. The authors discuss the need for "systematic restoration" which addresses the needs of the overall riparian ecosystem and can be accomplished through improving flows to reflect the natural hydrograph. The history of river restoration is briefly presented which leads to the current approach of instream flow needs (IFN) implemented through instream flow incremental methodology (IFIM). This approach links flow regimes with organism needs. Case studies were provided that show gradually decreasing flows (ramping flows) after a peak flood to fit into the "Recruitment Box Model" has permitted for increased seedling establishment of cottonwood and willow species and increasing minimum flows has assisted spawning of an endangered fish along a Nevada River while increasing seedling establishment. Finally, important issues with restoration implementation are presented. The authors caution that restoration is still a young science and as such, adequate study must be done before and afterwards to monitor river response and meet desired objectives.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Rood, S.B., J.H. Braatne, and F.M.R. Hughes. 2003. Ecophysiology of riparian cottonwoods: stream flow dependency, water relations and restoration. Tree Physiology 23: 1113-1124.	2003	Cottonwood ecophysiology	Literature review and synthesis	Northern hemisphere	Mainly semi-arid				*Populus*, cottonwood, groundwater, dam effects
Rood et al. (2003) reviewed ecophysiological studies performed on six different cottonwood species (*Populus* spp.). They provide five lines of evidence showing that cottonwoods depend on shallow alluvial groundwater originating from stream flow. Evidence includes cottonwood natural occurrence, decreases in cottonwood species resulting from dewatering and river damming, increases due to supplemental flow, isotopic analyses of xylem water, and physiological correlations of tree morphology and physiology with stream flow characteristics. Rood et al. discuss how stream flow promotes healthy riparian cottonwood stands via water availability, geomorphic disturbance for establishment, exclusion of upland vegetation, and transportation and deposition of seeds and propagules. Finally dewatering due to damming and its negative effects on cottonwood physiology and growth is discussed in detail and case studies are provided. The authors suggest water management via flow regulation downstream of dams to benefit cottonwoods.									
Rood, S.B., J.H. Braatne, and L.A. Goater. 2010. Responses of obligate versus facultative riparian shrubs following river damming. River Research and Applications 26: 102-117.	2010	Riparian Response to Flow Alteration	Peer Reviewed Basic Research	Snake River, Idaho, Oregon, and Washington, USA			Dammed - Hydroelectric		*Celtis reticulata*; hackberry; riparian ecology; instream flow needs; river damming; *Salix exigua*; Snake River; willow
Rood et al. (2010) studied the response of obligate and facultative riparian shrubs along the flow regulated Snake River in Hells Canyon. They found the difference between life histories of obligate and facultative species resulted in a transition of species presence due to flow regulation. Methods of comparative photography and hydrology (discharge data), are used to assess these effects. Observed in the photography from pre- and post-dam is a loss of sand, which it is hypothesized that the loss of sand trapped in the dams contributed to the loss of the obligate species (sand willow). It was also hypothesized that the loss of the disturbance characteristics of the natural flow regime further reduced the presence of the sand willow requiring barren substrates for establishment. In place of the sand willow, the facultative species (hackberry) increased. The management of the dam with peak daily flows occurring twice daily allowed for an irrigation effect for the hackberry, this coupled with its drought-tolerance, facilitated its survival. The findings of this study suggest the management of flow-regulated streams should use the necessary characteristics of the obligate species.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Rood, S.B., S.G. Bigelow, and A.A. Hall. 2011. Root architecture of riparian trees: river cut-banks provide natural hydraulic excavation, revealing that cottonwoods are facultative phreatophytes. Trees 25: 907-917.	2011	Cottonwood roots	Peer Reviewed Basic Research	Canadian Rocky Mountains: 6 rivers	Boreal		Free flowing and dammed		Poplars, *Populus*, Precipitation, Spruce, Water relations, Climate, Floodplain forests, Image analysis
Rood et al. (2011) developed the simple "cut-bank root method" to measure and analyze root distributions of trees along rivers. They photographed exposed roots of five different *Populus* spp. along meander cut banks on six rivers in the Canadian Rockies. The cut-bank method appeared to work best for coarse woody roots since fine roots were often removed or destroyed during cut-bank formation. Most cottonwood coarse roots were distributed linearly through the root profile, however some distributions were skewed with a band of shallow roots, or bimodal with two bands of concentrated roots. Major lateral roots appeared to branch horizontally with feeder roots branching off downward, so that there was a correlation between root depth and root extent. Rood et al. associated root distributions to environmental factors. Deeper roots were strongly positively associated with precipitation, with humid sites displaying mainly shallow rooted trees and drier sites with deeper rooted trees and the highest density of roots associated with the capillary fringe. As a result, cottonwoods were deemed "facultative phreatophytes" that grow deeper roots to access ground water only when grown in drier regions. Species differences were not significant and species root growth differed in different growing environments. According to these lines of evidence, damming or climate change that lowers river stage would result in drought stress and eventual mortality mainly for deep rooted phreatophyte cottonwoods that would then be unable to access groundwater, but would not have as great of an impact on shallower rooted cottonwoods in humid environments.									
Ruess, R.W., R. Hendrick, J.G. Vogel, and B. Sveinbjornsson. 2006. The role of fine roots in the functioning of Alaskan boreal forests. Pages 189-210 in F.S. Chapin III, M. Oswood, K. Van Cleve, L.A. Viereck, and D.L. Verbyla, editors. Alaska's Changing Boreal Forest. Oxford University Press, New York, NY.	2006	Fine root structure	Book Section	Interior Alaska	Boreal	Tanana	n/a		None
Ruess et al. (2006) review methods and results from studies estimating live fine root biomass and fine root growth in Alaskan boreal forests. Of note is the synthesis showing fine root dynamics in interior Alaskan forests differ from temperate and more southerly boreal ecosystems in that boreal systems have an approximately 6-week time lag between leaf out and maximum rates of fine root growth, which typically occur in mid-May, and mid-June to mid-July, respectively (Tryon and Chapin 1983, Ruess et al. 1998). Delayed soil warming rather than leaf-out may control fine root growth in northern boreal systems as at higher latitudes root elongation rates are more closely tied with soil warming trends. They document concentration of fine root production near the soil surface in cold boreal forests along the Tanana River. Annual production in the top 30 cm of a 1 m profile in the Tanana River study area showed an average of 87 ± 4% of annual production of fine root biomass versus only 50% of fine root biomass production in the top 30 cm in temperate forests.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Schmidt, J.C. and P.R. Wilcock. 2008. Metrics for assessing the downstream effects of dams. Water Resources Research 44: W04404. doi:10.1029/2006WR005092.	2008	Downstream Hydrologic Effects of Dams	Peer Reviewed Basis Research	Western United States			Dammed	4,000 km	None
Schmidt and Wilcock (2008) evaluate three metrics to represent downstream channel changes from dams – the metrics: 1) changes in sediment supply and transport capacity for sediment deficiency or surplus, 2) the Shields number for channel competence, and 3) a ration of pre- to postdam flood discharge for scale of channel change. Altered sediment supply conditions showed 67% of reaches were in a sediment deficit, while 4% were in surplus. $-0.08 < S^* < 1.61$. There is no general trend to channel incision, although it has been found under deficit condition, significant incision occurs when $\tau^* > 0.1$ and $S^* > 1$. Q^* ranges from 0.15 – 1.19 depending upon the purpose of the dam. To rehabilitate rivers below dams, the three characteristics identified in this paper must return to predam levels. The paper has little relation to the riparian ecosystem, and further agrees with the literature that to maintain a wild river requires the maintenance of the natural sediment and flow regimes.									
Scott, Kevin M. 1982. Erosion and Sedimentation in the Kenai River, Alaska. Geological Survey Professional Paper 1235. United States Department of the Interior. Washington, D.C.	1982	Erosion and Sedimentation	White-paper Report	Kenai River	Boreal		moraine-impounded lake (reservoir-like)	50 miles	None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Scott (1982) initiated a study on the Kenai River, a 50-mile salmon-spawning river in the Kenai Peninsula Lowlands that drains into Cook Inlet. High recreational activity, increase in observed erosion and decrease in bank stability led to Scott's study of erosion and sedimentation on the river. The intent is to determine the sedimentation system downstream of Skilak Lake (large moraine-impounded lake) and how it may affect aquatic habitat and spawning suitability. The primary anthropogenic factor studied is development associated with modifications to the main channel. Results include an increase in suspended-sediment concentrations. The increase is attributed to development along the river and is identified in order of significance on the sedimentation system: canals, groins and boat ramps, excavated boat slips, bank-protection structures and gravel mining and commercial developments. Erosion was quantified by comparison of aerial photographs. Comparisons showed the entrenched section of the river to be stable. In non-entrenched sections of river, expected erosion rates were observed. Eroding sections were found to be localized and unpredictable from channel configuration. Sections with the highest erosion rates correlated to anabranching reaches. Projected changes to the sedimentation system due to continued development is identified and corollary effects on the aquatic habitat are assessed.									
Scott, M.L., J.M. Friedman, and G.T. Auble. 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14: 327-339.	1996	Riparian Area Establishment	Peer Reviewed Basic Research	Missouri River, Montana, USA			Free Flowing - effectively		None
Scott et al. (1996) assess the conditions at which bottomland cottonwood, poplar, and willow can establish from seed. Three major fluvial processes are identified, (1) narrowing, (2) meandering, and (3) flood deposition that create the necessary bare, moist surfaces protected from disturbance. All three fluvial processes are associated with different flows, and create different spatial and temporal patterns of trees. The narrowing fluvial condition gives rise to variable patterns that are usually not-even aged, and establish at relatively low elevations in the channelbed. The meandering geomorphic process gives rise to establishment on point bars, and stands with patterns that are arcuate and even aged, with asymmetry between banks, flood trained stems, and buried root collars. Infrequently flood depositional conditions arise which produce stands characteristically linear, even-aged, little flood-training of the stems, and well above the channel bed elevation.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Scott, M.L., G.C. Lines, and G.T. Auble. 2000. Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. Journal of Arid Environments 44: 399-414.	2000	Cottonwood Related to Groundwater Decline	Peer Reviewed Basic Research	Mojave River, California, USA	Arid		Agricultural Dam	8 km	alluvial ground-water; channel incision; *Populus*; redoximorphic features; riparian vegetation; water-table declines
Scott et al. (2000) assessed lowered water-table levels following flood-related channel incision on the vigor and mortality of cottonwoods. The studied reach with reduced cottonwood vigor and mortality had a water table decline of 0.71 to 3.6 m from 1963 and 1997. Well records and soil redoximorphic features indicate a threshold in cottonwood success, and stress and mortality. Water-table declines greater than or equal to 1.5 m resulted in 58 to 93% mortality and reduced vigor for surviving trees, and declines less than 1.0 m stand mortality was 7 to 13% - sustained reductions of even 1 m in coarse alluvial flood-plain soils can threaten physical process of riparian cottonwoods.									
Scott, R.L., E.A. Edwards, W.J. Shuttleworth, T.E. Huxman, C. Watts, and D.C. Goodrich. 2004. Interannual and seasonal variation in fluxes of water and carbon dioxide from a riparian woodland ecosystem. Agricultural and Forest Meteorology 122: 65-85.	2004	CO2 and water flux	Peer Reviewed Basic Research	Arizona/Mexico	Semiarid				Evapotranspiration; Carbon dioxide exchange; Eddy covariance; Energy balance; Riparian vegetation; Mesquite; *Prosopis velutina*
Scott et al. (2004) used a variety of methods to measure water, energy, and carbon dioxide flux in a mesquite woodland along the San Pedro River in Arizona. Due to increased urbanization and possible drawdown of groundwater, the authors wished to determine how the riparian forest used groundwater. They found that mesquite trees relied on groundwater, while other understory plants depended upon precipitation. They described in depth the patterns of seasonal forcing and stand energy balance, diurnal latent heat and carbon dioxide flux, and water and carbon dioxide flux during the spring, pre-monsoon monsoon, and autumn time periods. Overall they concluded that mesquite are not currently water limited and they appear to fix carbon throughout the growing season. However, with monsoons, the understory vegetation becomes more active and microbial respiration increases dramatically, causing the ecosystem to be a net source of carbon dioxide. Therefore, this vegetation and microbes especially, appear to be strongly water limited. Finally, the authors proposed their plans to develop an evapotranspiration model to predict future water use of this ecosystem.									
Segelquist, C.A., M.L. Scott, and G.T. Auble. 1993. Establishment of *Populus deltoides* under simulated alluvial groundwater declines. American Midland Naturalist 130(2): 274-285.	1993	Groundwater Effects on Populus	Peer Reviewed Basic Research						*Populus*, cottonwood, groundwater
Segelquist et al. (1993) use a laboratory setting to assess the survival of plains cottonwood (*Populus deltoides* subsp. *monilifera*) under five treatments of alluvial groundwater decline. Treatments were saturated conditions, and decline rates of 0.4, 0.7, 2.9 cm/d and immediate drawdown. Survival was highest in treatment one (saturated conditions), but biomass, shoot height and mass, and root length and mass were highest for treatment two (0.4 cm/d decline). During the experiment 12.0 cm of natural precipitation occurred, suggesting that cottonwood cannot germinate survive on precipitation alone, even though experimental design didn't evaluate for precipitation alone. Of interesting note was that even with varying water table decline rates, there wasn't a significant difference of root length across treatments, but declines support greater growth rates than saturated conditions. These findings of survival and associated biomass metrics, suggested that the slight decline of 0.4 cm/d allowed for the healthiest plants, with the highest ability to resist flood scour and ice effects.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Shafroth, P.B., A.C. Wilcox, D.A. Lytle, J.T. Hickey, D.C. Andersen, V.B. Beauchamp, A. Hautzinger, L.E. McMullen, and A. Warner. 2010. Ecosystem effects of environmental flows: modeling and experimental floods in a dryland river. Freshwater Biology 55: 68-85.	2010	Environmental Flows and Riparian Vegetation - Computer Model	Peer Reviewed Basic Research	Blue Williams River, Arizona, USA	Arid and Semi-Arid	13,000 sq km	Flood Control Dam		beaver, benthic macroinvertebrates, fluvial geomorphology, physical habitat modeling, riparian vegetation
Shafroth et al. (2010) use the Blue Williams River and the Alamo dam, a part of the Sustainable Rivers Project, to seek to improve the knowledge and predictions of ecological responses to environmental flows. Two general advancements are sought, (1) coupling physical system models to ecological responses, and (2) clarifying empirical relationships between flow and ecological responses through implementation and monitoring of experimental flow releases. The entirety of the model incorporated, (1) a reservoir operations model to simulate releases and water levels, (2) one- and two-dimensional river hydraulics models to simulate stage-discharge relationships at the whole river and local scales, and (3) a groundwater model to estimate surface- and groundwater interactions. The model was used to develop hydrology-ecology relationships for riparian seedling establishment, seedling mortality, beaver dam persistence and invertebrate guild dynamics. General themes that emerged included the importance of response thresholds, and the importance of spatial and temporal variation in the effects of flows on ecosystems. To create a more quantitative understanding of the hydrology-ecology relationship a library is being create detailing response curves.									
Shafroth, P.B., G.T. Auble, J.C. Stromberg, and D.T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18(4): 577-590.	1998	Seedling establishment	Peer Reviewed Basic Research	Bill Williams River, Arizona	Arid	13,700 sq km	dammed	69.5 km	seedling establishment, *Populus*, *Salix*, *Tamarix*, *Baccharis*, streamflow, water table, Arizona
Shafroth et al. (1998) studied the patterns of recruitment for four woody species: *Populus fremontii, Salix gooddingii, Baccharis salicifolia*, and *Tamarix ramosissima*, in relation to reservoir releases after two of the highest possible controlled discharges on the Bill Williams River in 1993 and 1995. They wished to test and extend the Recruitment Box Model for arid species and along multiple river reaches. Germination occurred mainly where it was predicted: in zones with low basal area, greater light values, and greater herbaceous cover. Maximal survivable water declines varied by species, but were between 1.2-4.4 cm/day in 1993 and 2.8-4.2 cm/day in 1995. Each species also had a different maximum depth to water table requirement for establishment. Depth of inundation following establishment did not vary at plots with and without seedlings. However, soil electrical conductivity was slightly higher in plots without seedlings (significantly for *S. gooddingii*). The authors found that the existing Recruitment Box Model applied to all four species along the Bill Williams, and that their germination model which included water-surface levels and seed dispersal phenology was a strong predictor of where seedling establishment would occur, and this varied spatially by species. Overall they conclude that in order to maintain healthy populations of multiple species versus a single species, prescribed flows need to vary over multi-decadal time scales and an understanding of effective prescribed flows can be obtained from studying reach variations in stage-discharge relationships, the wetted perimeter, water-table depths, and basal area.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Shafroth, P.B., J.M. Friedman, G.T. Auble, M.L. Scott, and J.H. Braatne. 2002. Potential responses of riparian vegetation to dam removal. BioScience 52(8): 703-712.	2002	Riparian Vegetation following dam removal	Literature review and synthesis	United States					None
Shafroth et al. (2002) discuss how riparian vegetation responds to dam removal and present a few case studies as examples. In general, dam removal can restructure vegetation through changing the hydrological regime, creating new areas of bare sediment above and below the dam site, or distributing sediment with different physical and chemical characteristics. After dam removal, downstream effects include a sediment pulse and accretion which may encourage colonization of riparian vegetation, though vegetation burial by sediment could also occur. Downstream effects also include a change to a naturalized flow regime which will likely encourage restoration of native plant communities. Positive effects such as these were seen on the Elwha River, WA. Upstream responses to dam removal include initial mortality of vegetation at the margins of the former reservoir, and a transition phase with extensive colonization of bare areas, potentially by invasive species, as was seen with small dam removal in Wisconsin. Restoration after dam removal is subject to several factors such as climate, flood regime, and geology, and the legacy of flow regulation can result in a delayed rehabilitation. The authors provided several considerations during dam removal including managing the transient sediment pulse for beneficial outcomes (such as native forest regeneration on transient sediments), controlling the timing and pattern of reservoir drawdown, managing vegetation establishment to avoid invasion by invasive species, creating habitat diversity, and improving recreational use of the river.									
She, Yuntong, Faye Hicks, and Robyn Andrishak. 2012. The role of hydro-peaking in freeze-up consolidation events on regulated rivers. Cold Regions Science and Technology 73: 41-49.	2012	Hydropeaking and ice freeze-up	Peer reviewed Basic Research	Peace River, Canada	Boreal		hydroelectric		river ice, ice jams, numerical modeling, river freeze-up
She et al. (2012) study the correlation between hydro-peaking and ice-cover development on the Peace River in northern Alberta through hydrodynamic ice processes modeling. The one-dimensional model, River1D, which includes both thermal and dynamic ice processes, was used in order to predict ice profile and water levels associated with ice cover consolidation. A consolidation event in 1982 on the Peace River was simulated in River1D. The model was successful in creating an ice jam of comparable height, thickness and length to the 1982 observed ice jam. Through additional model scenarios, the rapid advancement of the ice front in extremely cold temperatures was found to be the dominant factor controlling thickness and height of the ice jam. Hydro-peaking was a minor factor in the modeling of the 1982 ice jam. It remains unknown if hydro-peaking in the absence of a warming spell can trigger the break-up of ice cover. Meteorological factors were found to be significant controls in ice cover consolidation events on a regulated river.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Sheppard, L.A., A.M. Brunner, K.V. Krutovskii, W.H. Rottmann, J.S. Skinner, S.S. Vollmer, and S.H. Strauss. 2000. A DEFICIENS homolog from the dioecious tree black cottonwood is expressed in female and male floral meristems of the two-whorled, unisexual flowers. Plant Physiology 124:627-639.	2000	Black cottonwood genetics	Peer reviewed basic research						cottonwood
Sheppard et al. (2000) isolated and described the structure and function of a MADS box gene from black cottonwood trees: PTD. This gene resolved as a member of the TM6 subgroup within the DEF/AP3/TM6 family, and it is the first nonastrid gene described in the TM6 subgroup. This subgroup contains transcription factors such as DEF from snapdragons and AP3 from Arabidopsis that appear to perform similar functions to PTD. The authors found that PTD is not expressed in vegetative tissues but is strongly expressed in the floral meristem that gives rise to stamen primordial although PTD is absent from carpel primordial. Since expression of this gene is not detected until after the meristem has formed is seems unlikely that this gene is directly involved in sex determination. However, PTD has a role in development of reproductive tissues, and the authors state this gene could thus be useful for engineering sterility in transgenic insect/herbicide resistant trees to increase the possibility of transgene containment.									
Smith, Derald G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. Geological Society of America Bulletin 87: 857-860.	1976	Bank Erosion and Stability	Peer reviewed Basic Research	Alexandra River, Alberta	Boreal				fluvial geomorphology, channel stability, river-bank vegetation, anastomosed channels, erosion box
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Papa, Prigent and Rossow (2007) examine the spatial and temporal variations of monthly inundation extents of the boreal Ob River basin through satellite and in-situ data collection. Results indicated a strong correlation between inundation extent and snowmelt parameters in the southern (more upstream) region of the watershed. In the northern (more downstream) region of the watershed, inundation (i.e., flooding) correlated more strongly to the amount of contributing water from the upper watershed. The study identifies the methods used as an adequate way to determine seasonal and interannual variations of inundation in a large watershed that exhibits a snow-inundation-runoff relationship.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Smith, Derald G. 1979. Effects of Channel Enlargement by River Ice Processes on Bankfull Discharge in Alberta, Canada. Water Resources Research 15: 469-475.	1979	Ice effect on channel geometry	Peer reviewed Basic Research	Albertan rivers	Boreal		free-flowing		None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Smith (1979) investigates 24 rivers in a boreal region (Alberta, Canada) in order to identify factors that may cause differences in typical bankfull discharges, return periods and channel areas from typical values established from temperate climate rivers. All studied rivers were free-flowing and had the presence of adjacent to or near a gaging station. Bankfull recurrence intervals in northern rivers were calculated on average to be 16.7 years versus 1.6 years in more temperate climates. Smith contends that the difference in return period frequency may be due to channel enlargement by ice-processes. Further magnitude, frequency and duration of river ice are suggested as the primary channel-shaping process in many Albertan rivers.									
Smith, Derald G., and Cheryl M. Pearce. 2002. Ice jam-caused fluvial gullies and scour holes on northern river flood plains. Geomorphology 42: 85-95.	2002	Ice Processes	Peer-reviewed Basic Research	Milk River (Alberta, Montana)	temperate		free-flowing		Gullies; Scour holes; Ice jams; Fluvial processes; Meander lobes; Flood plains; Milk River
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Smith and Pearce (2002) investigated correlations between ice-jam induced overbank flow and the formation of gullies and scour holes on the floodplain. Observations of these geomorphic features were compiled from the Milk River in Southeast Alberta and Northcentral Montana. Most meanders on the Milk River correlated with the presence of ice-scars on trees and most meander lobes had gravel rafted across the surface. As expected, meander lobes with adjacent sharp channel bends were most prone to ice-jams. Corresponding ice-induced rerouted flow at these locations was found to cause gullies and scour holes. Observations also indicate that repeated erosion of a gully over time due to ice-jams can result in a chute channel or U-shaped oxbow lake and may be the primary process that forms these features.									
Stella, J.C., J.D. Riddle, J.J. Battles, M.K. Hayden, and A.K. Fremier. 2012. Riparian forest dynamics on a large, regulated river (California, USA): impacts and implications for management. Proceedings of the Integrative Sciences and Sustainable Development of Rivers (IS Rivers) Conference. Lyon, France, 26-28 June 2012.	2012	Riparian Response to Flow Alteration	Conference Paper	Sacramento River, CA, USA	Temperate		Dammed	160 km	Chronosequence, climate change, *Populus*, riparian forest dynamics, river management, *Salix*.
Stella et al. (2012) produced a chronosequence for the Sacramento river to assess the forest structure and successional patterns following river damming. The river has been regulated for 70 years, and stands ages 40-60 years of age were the most extensive in floodplain area; these stands also represented the highest values of biomass, species diversity, and functional wildlife habitat. Through the successional trajectory, the dominant trees shifted from willow to cottonwood to walnut and maple species. Following approximately 90 years, the point bars these floodplain forests survive on begin to degrade through a loss of basal area and quantity of large trees. Managing channel migration is key to maintaining healthy, dynamic, and multi-aged floodplain forest structures.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Stella, J.C., J.J. Battles, J.R. McBride, and B.K. Orr. 2010. Riparian seedling mortality from stimulated water table recession, and the design of sustainable flow regimes on regulated rivers. Restoration Ecology 18(52): 284-294.	2010	Seedling survival	Peer Reviewed Basic Research	San Joaquin Basin, CA	Semi-arid				environmental flow, Populus, river regulation, Salicaceae, *Salix*, seedling establishment, survival analysis, water table decline.
Stella et al. (2010) completed an experiment mimicking a range of flow recession rates typical of free flowing and damned rivers in the San Joaquin Basin, CA. They evaluated the effects of flow recession on three species: *Populus fremontii* (POFR), *Salix gooddingii* (SAGO), and *Salix exigua* (SAEX). They found that drawdown rate had a strong influence on seedling mortality, though there were differences between species: SAGO had consistently high survival across the drought gradient while POFR was more sensitive to drought stress. Using AFT modeling they showed that to achieve 25% survival after 60 days of drawdown POFR required no more than 2.25 cm/day recession, while SAEX could survive with 2.75 cm/day and SAGO with 3.5 cm/day. The authors compared the experimental findings to several different years of recession data from the Tuolumne River and discussed how flow regulation and certain drawdown scenarios could induce species level differences in recruitment success and ultimately change community structure due to differential survival. Finally, they stated that regulated flows need to occur at the correct times coinciding with seed dispersal and at the right rate of change to allow for seedling survival.									
Stella, J.C., J.J. Battles, B.K. Orr, and J.R. McBride. 2006. Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California. Ecosystems 9: 1200-1214:	2006	Seed dispersal	Peer Reviewed Basic Research	California-Tuolumne River	semiarid	35000 sq km	Dam - multiple	240 km	phenology; seed dispersal; degree-day model; seed longevity; germination; Populus; Salix; seedling recruitment; riparian habitat restoration; flow regulation; California central-valley.
Stella et al. (2006) evaluated seed release, longevity, and viability for three tree/shrub species along the lower Tuolumne River in the San Joaquin Basin, CA. They developed a degree day model to predict annual seed release of two tree species: *Populus fremontii* (POFR) and *Salix gooddingii* (SAGO) and one clonal shrub: *Salix exigua* (SAEX). Peak seed release was related to the spring snowmelt runoff pulse: peak POFR seed release occurred during maximum spring runoff and SAGO and SAEX peak seed release occurred after maximum flooding. The degree day model accurately predicted seed release timing for the two tree species but less so for the shrub. The authors concluded that seasonal temperature patterns are responsible for the correlation between seed release and spring snowmelt runoff pulse for the two tree species. However, they caution that there appears to be strong local and ecotypic influences on the timing of seed release and in order to use this type of model for an entire river basin a broad range of sites should be selected. If this is done a degree day model can be developed using only two to three years of sampling data.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Stella, J.C., M.K. Hayden, J.J. Battles, H. Piegay, S. Dufour, and A.K. Fremier. 2011. The role of abandoned channels as refugia for sustaining pioneer riparian forest ecosystems. Ecosystems 14: 776-790.	2011	Pioneer tree establishment	Peer Reviewed Basic Research	Sacramento River, CA	semiarid	68,000 sq km	Dam	160 km	abandoned channel; cottonwood; Salicaceae; floodplain; recruitment refugia; riparian; Sacramento River; dendrochronology; oxbow; persistence strategy
Stella et al. (2011) used aerial photography, dendrochronology, and surveying techniques to evaluate the importance of abandoned river channels as spatial refugia for pioneer tree species. Pioneer tree recruitment in these areas requires change from an aquatic environment to a terrestrial environment via channel cutoff, bedload infilling, dewatering, and fine sedimentation followed by vegetation colonization. The authors found that along the Sacramento River, CA, 54% of the total forest area was associated with channel abandonment and that cottonwood forests developed 15-100 years after channel cutoff with successive recruitment occurring for 4-40 years. Initial and continued colonization appeared to depend on the rate at which a channel filled, with slowly filling channels creating a competitive environment less quickly and permitting continued colonization by pioneer cottonwoods. Site age was a significant predictor of abandoned channel elevation and this could also decrease colonization by pioneer trees due to less frequent flooding. The authors stated that abandoned channels are important in the long-term persistence of pioneer riparian tree populations especially along rivers subject to damming or substantial climate change impacts.									
Stickler, Morten, Knut T. Alfredsen, Tommi Linnansaari, and Hans-Petter Fjeldstad. 2010. The influence of dynamic ice formation on hydraulic heterogeneity in steep streams. River Research and Applications 26: 1187-1197.	2010	Ice Processes	Peer-reviewed Basic Research	River Sokna, Norway, Southwest Brook Canada, and Catamaran Brook, Middle reach, Canada	Boreal	37-539 km^2	free flowing		Ice processes
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. In Stickler et al.'s (2010) study on three unregulated steep boreal streams, the impacts of dynamic ice formation on in-channel heterogeneity was quantified. In an effort to isolate the impacts of ice formation from discharge, anchor ice formation was studied during periods of minimal changes in flow. The three rivers, river Sokna, Norway, Southwest Brook, Canada and Catamaran Brook, Canada, are small streams dominated by fast-flow water. Changes in wetted area, longitudinal water elevation, water depth, and mean water velocity and changes in in-stream hydraulic complexity through hydromorphological units (HMUs) were quantified on established transects. A total of five freeze-up events were studied among the three streams. Results identified significant backwater effects including increased wetted areas, water depths and reduced water velocities from formation of anchor ice and anchor ice dams. This dynamic ice formation was found to contribute to stable static ice cover. The observed ice effects occurred independent of large changes in discharge and suggest a reduced role of discharge as the primary controller of in-stream morphology in steep streams that experience ice formation.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Stoffel, M. and D.J. Wilford. 2012. Hydrogeomorphic processes and vegetation: disturbance, process histories, dependencies and interactions. Earth Surface Processes and Landforms 37: 9-22.	2012	Riparian vegetation and hydrogeomorphology	Literature Review						hydrogeomorphic processes; riparian vegetation; dendrogeomorphology; alluvial fans; debris-flow cones; forest management; risk analysis
Stoffel and Wilford (2012) sought to describe the complex ways vegetation and hydrogeomorphic processes interact along rivers. Vegetation controls erosion and runoff along rivers, removal of vegetation can increase runoff, peak flows, and increase channel sediment mobilization, erosion, and destabilization of river fans and stream channels. Riparian vegetation contributes to the morphology of the river by preserving the channel width, stabilizing the riparian zone, and contributing large woody debris which in turn can further stabilize the river bed and banks and create new areas for vegetation colonization. River hydrogeomorphic processes can disturb vegetation through killing and removing, injuring, tilting, burying, or exposing plant roots. The authors focus on how tree ring analysis can be used to date such past events. This process allows for particularly hazardous locations along the river to be identified, reconstruction of historical processes on fans and banks, reproduction of past flow conditions and streampower, etc. Throughout, the authors provide several case studies throughout the world where this method has been used to show different interactions between vegetation and river hydrogeomorphology.									
Strom, L., R. Jansson, C. Nilsson, M.E. Johansson, and S. Xiong. 2011. Hydraulic effects on riparian vegetation in a boreal river: an experiment testing climate change predictions. Global Change Biology 17(1): 254-267.	2011	Climate Change and Riparian Community Response	Peer Reviewed Basis Research	Vindel River, Sweden	Boreal	12,654 sq km	Free Flowing	455 km	biomass, climate change, flooding, productivity, reciprocal transplant experiment, river banks, species composition, species richness, water table, wetlands
Ström et al. (2010) used transplant experiments and projected streamflow from IPCC climate change scenarios to predict likely changes in riparian vegetation in boreal rivers. Riparian plant communities are projected to be replaced by terrestrial communities at high elevations due to lower magnitude spring floods, and amphibious and aquatic communities at low elevations due to higher autumn and winter flows. An overall result will be less area for riparian species resulting in lower species abundance. Transplanting experiments showed when low elevation plants were moved to higher ground, biomass decreased and species richness increased; while high elevation plants increased in biomass and decreased in species richness. Climate is expected to warm resulting in lower winter snow pack and lower late-spring floods, and with warmer temperatures higher fall and winter flows will be seen – this will reduce the hydrologic variability in boreal regions.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6(1): 113-131.	1996	Riparian vegetation response to groundwater decline	Peer Reviewed Basic Research	San Pedro River, Arizona	Semi-arid	6390 sq km	Groundwater pumping		ecosystem degradation; floodplain aquifer; groundwater decline; indicator species; Populus fremontii; riparian ecosystem; San Pedro River, Arizona; semiarid alluvial habitat; weighted average wetland indicator score
Stromberg et al. (1996) predict the effect of groundwater depletion on riparian and aquatic herbaceous and woody plant species. The composition of riparian vegetation is most influenced by the depth to ground water (which coincides with floodplain elevation and inundation frequency), followed by soil texture and moisture holding capacity, light availability, and site elevation, however the specific impacts of each are difficult to parse out because of their interactions. The authors described individual plant species and their ideal depths to groundwater and how the four different wetland types they make up would change in abundance with a change in groundwater. With a decrease in groundwater depth of 0.3 m, obligate wetland plant habitat would decrease by 28%, and with a decrease of only 1 m it would be extirpated. The wetland indicator group (facultative upland) that had the greatest depth to groundwater requirements would increase in abundance. Overall, species associated with shallow groundwater had the narrowest range of depth to groundwater requirements, and herbaceous species had narrower requirements than woody species. Plants with wider ranges included facultative, facultative upland, and obligate wetland species, but their size and productivity could potentially be affected by declines in groundwater. Finally, succession could be disrupted due to loss of pioneer species with shallow groundwater requirements that also act as ecosystem engineers (via sediment capture and accretion) and this would also lead to a net loss of biodiversity.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Svendsen Kristen M., Carl E. Renshaw, Francis J. Magilligan, Keith H. Nislow, and James M. Kaste. 2009. Flow and sediment regimes at tributary junctions on a regulated river: impact on sediment residence time and benthic macroinvertebrate communities. Hydrological Processes 23: 284-296.	2009	Dam effect on tributaries	Peer-reviewed Basic Research	West River in eastern Vermont	temperate		flood control		flow regulation, dams, isotopes, macroinvertebrates, tributary junctions
Svendsen et al. (2009) quantify changes in sediment transport and channel bed morphology at tributary junctions on the West River due to flow regulation by identification of sediment residence time at tributary junctions. Short-lived fallout radionuclide beryllium-7 was used as an indicator of sediment transport. Benthic community structure (relative abundance of caddisflies and mayflies) was compared with coarse sand-sized sediment residence times. Comparisons were then made between sediment transport dynamics and benthic community responses in attempt to identify a method for understanding ecological response of changes in the hydrologic and sediment regime. The West River, downstream from regulation was found to transition from bed degradation to aggradation in part due to flow and sediment influx from tributaries. The mainstem however is no longer capable of mobilizing some sediment from larger tributaries contributing to bed aggradation and formation of cobble and sand bars at tributary junctions and increased mobilization of finer sediment below tributary confluences. Seasonal variations in benthic population at tributary junctions complicate its correlation with sediment. However, the reduction of the mayfly to caddisfly ratio with sediment radionuclide activity during late summer suggests caddisflies prefer low transitional bedload sediment residence time (i.e., more stable sites). Because flow regulation maintains a relatively stable main channel, some benthic communities are predicted to be more successful than others potentially modifying the benthic community structure.									
Syvitski, James P.M. 2002. Sediment discharge variability in Arctic rivers: implications for a warmer future. Polar Research 21, no. 2: 323-330.	2002	Climate change and sediment loading	Peer-reviewed Basic Research	Arctic and sub-arctic rivers	Boreal	90 km^2 to 2,929,000 km^2	free-flowing		None
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Syvitski (2002) analyzes the sediment load from Arctic and sub-Arctic rivers and develops a model for estimating sediment flux based on changing temperature conditions. The study identifies a range of Arctic and sub-Arctic drainage basins (90 km^2 to 2,929,000 km^2) located in Russia, Canada or the US for sediment flux analysis. On rivers with reservoirs, pre-dam sediment variables are used. Application of a global model to predict sediment load on the studied rivers finds that drainage basin temperature is a major variable corresponding to sediment production and transport. This may explain why many Arctic rivers produce a lower sediment lower than those in temperate climates. Syvitski hypothesizes that this may be due to hydrological cycle feedbacks where the extent and influence of frozen soil and snow-melt will produce a different sediment loading compared to the more direct effect of rainfall on sediment loading. Moreover, these findings suggest an increased sediment flux from Arctic rivers due to increased global temperatures. Predictions indicate that for every 2 degrees Celsius temperature increase there will be a 22 percent increase in sediment flux in rivers and streams and for every 20 percent increase in discharge there will be a corresponding 10 percent increase in sediment load.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Takashi Gomi, Roy C. Sidle, Mason D. Bryant, and Richard D. Woodsmith. 2001. The characteristics of woody debris and sediment distribution in headwater streams, southeastern Alaska. Canadian Journal of Forest Research 31: 1386-1399.	2001	LWD recruitment	Peer reviewed Basic Research	Southeast Alaska	Boreal		free-flowing		large woody debris, riparian vegetation
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Gomi et al. (2001) measured wood characteristics, wood recruitment, and sediment deposition zones in high-gradient headwater streams in southeast Alaska. Wood was characterized as large woody debris (LWD), fine woody debris (FWD), and fine organic debris (FOD). Clear-cut logging was observed to create large sediment accumulation sites within the streams. In a comparison of LWD quantity on streams with younger forest stands (conifers) or clear-cut versus old-growth forest stands, FWD presence was found to be relatively similar on all stream reaches while LWD was less prevalent in the old-growth forest streams. Recent scour or landslide events were found to reduce the quantity of LWD or FWD in the streams. The existence of sediment zones was correlated with large numbers of both LWD and FWD and conversely large quantities of sediment were observed behind LWD and FWD accumulation. Overall, both natural and anthropogenic influences were found to alter the studied streams. The study notes that logging slash, landslides and debris flows, and regeneration of riparian stands are three aspects of disturbances that should be incorporated into any management programs of headwater streams.									
Takashi Gomi, Roy C. Sidle, Richard D. Woodsmith, and Mason D. Bryant. 2003. Characteristics of channel steps and reach morphology in headwater streams, southeast Alaska. Geomorphology 51: 225-242.	2003	Channel Steps and Reach Morphology	Peer reviewed Basic Research	16 headwater streams in southeast Alaska	Boreal		free-flowing		Forest streams, woody debris, channel morphology, timber harvesting, mass movement, riparian vegetation
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Gomi et al. (2003) evaluate the significance of woody debris input through timber harvesting and increased sediment supply through mass movement on the effect of channel steps and reach morphology in 16 headwater streams in southeast Alaska. The paper discusses the structure and geometry of channel steps that are formed by woody debris, boulders, and bedrock, analyzes the distribution and types of channel reaches that correspond to different channel steps (i.e., pool-riffles, step-pools, step-steps, cascades, rapids, and bedrock), and evaluates the effect of mass movement and woody debris input on channel steps and reach morphology. Woody debris input from timber harvesting was typically found to be immobile by the narrow headwater stream and resulted in the development of channel steps. The corresponding channel reach types may therefore be modified from step-pools to step-steps. Pool-riffle and step-pool reaches were found to be dominated by fluvial processes while colluvial processes dominated in bedrock reaches. Step-step, rapids, and cascade reaches were influenced by both fluvial and colluvial processes. Mass movement was found to cause scour, runout, and deposition of woody debris and sediment that subsequently altered channel type and reach morphology.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Tanaka, N. and J. Yagisawa. 2012. Index of medium-class flood disturbance for increasing diversity of vegetation area at gravel bars or islands in middle of rivers. International Journal of River Basin Management 10(3): 255-267.	2012	Flood disturbance influence on riparian vegetation	Peer reviewed basic research	Arakawa and Tamagawa Rivers, Japan	Temperate	2940 sq km and 1240 sq km		173 and 138 km	Flood disturbance; biodiversity; moment by drag force; shear stress; gravel-bed river
Tanaka and Yagisawa (2012) investigated how flood drag moment and shear stress influence vegetation breaking or washout in order to understand what types of flooding permits an increase in plant biodiversity but slows down forestation within the river channel. They studied several tree and grass species in two rivers in Japan, the Arakawa and Tamagawa Rivers. They determined the parameters: WOI (washout index) and BOI (breaking/overturning index) and the conditions that would contribute to the critical limit for both in each river. The shear stress at the river bed explained washout conditions of trees better than the moment and the critical shear stress was determined to be influenced by bed materials. The WOI was slightly affected by the BOI and differs between species due to differences in root systems, but the difference between grasses and trees was not significant. The authors also delineated five regions on each of three islands within each river depending on flood possibility (height of region above channel). For each island region they determined the relationship between flood disturbance index and plant biodiversity. An intermediate disturbance index correlated with the highest biodiversity similar to the "intermediate disturbance hypothesis" proposed by Connell (1978) in tropical rainforests.									
Theiling, C.H. and J.T. Burant. 2013. Floodplain inundation mapping for integrated floodplain management: Upper Mississippi River System. River Research and Applications 29: 961-978.	2013	Floodplain Inundation Modeling	Peer Reviewed Basis Research	Upper Mississippi River, USA		49,209 sq km	Dammed	1609 km	Upper Mississippi River; flood inundation; hydrology; geomorphology; ecosystem services; integrated floodplain management
Theiling and Burant (2013) created a model using the one-dimensional flood stage outputs of HEC-RAS and the high-quality DEM models of GIS to map flood inundations of >1000 miles of the Upper Mississippi River System under varying flood conditions – floods varied from the 2-year to the 500-year event. The analysis documents, 1) the effects of impoundments, 2) a hydrologic gradient within navigational pools that creates repeating patterns of riverine, backwater, and impounded aquatic effects, 3) the floodplain inundation patterns for the 1000 miles of river (~2 million acres), and 4) several integrated floodplain management scenarios. The paper has little pertaining to floodplain forests, however the modeling combination of HEC-RAS and GIS has a strong potential for mapping our scenarios under flooding conditions.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Tockner, K., F. Mallard, and J.V. Ward. 2000. An extension of the floodpulse concept. Hydrological Process 14: 2861-2883.	2000	Fluvial and biological process	Peer Reviewed Basis Research	Val Roseg River, Switzerland; Tagliamento River, Italy; Dunabe River, Austria	Temperate		Free Flowing		river, floodplain, flow pulse; temperature; ecosystem process; expansion; contraction; biodiversity; conservation; landscape
Tockner et al. (2000) extend the flood pulse concept to upper and middle reaches of rivers in temperate regions. Taking special attention to temperature's role in floodplain ecology, and the expansion-contraction cycles below bankfull ("flow-pulse"), a landscape approach is used to assess the role of the flow-pulse on landscape heterogeneity, connectivity, functional process, and biodiversity. Within upper and middle reaches the importance of below bankfull dynamics, using the flow-pulse concept, is important in the determination of the functional state at which the river is in. Three stages of river connectivity are established to differentiate these states, 1) disconnection phase, 2) seepage connection phase, and 3) surface connection phase. As these systems move through these phases, the role of allochthonous and autochthonous nutrients plays a large role in biological development. The expansion of the flood pulse concept to the flow pulse concept within this paper primarily focuses upon fauna, and not flora, however discussion of the importance of connectivity to the floodplain forest for nutrients and habitat is extensive.									
Tuthill, A.M., K.D. White, C.M. Vuyovich, and L.A. Daniels. 2009. Effects of proposed dam removal on ice jamming and bridge scour on the Clark Fork River, Montana. Cold Regions Science and Technology 55: 186-194.	2009	Effects of Dam on Ice Processes	Peer reviewed Basic Research	Clark Fork River, Montana	temperate		other		Ice jams, Ice jam bed scour, Ice jam modeling, Dam removal, Remediation of contaminated sediment, Clark Fork River, Superfund Project
Tuthill et al. (2009) modeled the potential effects of dam removal on ice-jam formation and associated bridge scour on the Clark Fork River, Montana. The HEC-RAS hydraulic model was used to simulate freezeup covers and breakup jams for pre-and post-dam removal scenarios. Model results suggest that increased potential of ice-jam induced flooding and scour were not likely. Ice-cover would change due to dam removal and sheet ice on existing impoundments is expected to change to accumulations of shoved frazil ice resulting in a 30% increase of total ice volume in the study area. The location of the most severe ice-jam flooding event in recent history is predicted to remain a jam location because the sharp bend, slope reduction and gravel flats that make this a preferential jam location will remain relatively unchanged. The ice jam stability analysis and field observations of existing ice conditions suggest that the channels will convey breakup ice past Missoula without jamming. Under-ice scour is predicted to increase post dam removal. Additionally, bank protection (designed for the 100-year open water flood) is predicted to resist scour due to ice and hydraulic conditions however it is still possible for an ice jam to cause scour in excess of bank protection capabilities.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
University of Alaska Agricultural and Forestry Experiment Station. 1985. Riparian vegetation succession report. Alaska Power Authority. Susitna Hydroelectric Project. APA Document 3099.	1985	Succession	White Paper Report	Susitna	Boreal	50,764 sq km	Free-flowing	504 km	Succession, Susitna
University of Alaska (1985) presented an in depth description of existing Susitna River geomorphology, vegetation, and moose browse dynamics and suggested what could occur if the Susitna Hydroelectric Project was constructed in the 1980s. They discuss the geomorphological history of the Susitna as well as the effects on geomorphology of river ice and sediments. Vegetation successional patterns were described in detail. The plant species, cover, density, and ages found at early, intermediate, and late successional sites were discussed and a conceptual model for how vegetation succession progresses at these sites was presented. Processes occurring during different successional stages such as: colonization and seed dispersal, establishment, ice effects, substrate deposition and erosion, and winter ice cover were described. The authors presented the idea that vegetation can be caught in cycles during succession due to processes like ice effects. Finally, they presented their ideas for how dam construction would affect the geomorphology and vegetation along the Susitna, and a few ideas for mitigation of dam effects such as logging or prescribed burning of mature paper birch/white spruce sites to provide continued moose browse production.									
University of Alaska Agricultural Experiment Station. 1982. Subtask 7.12: Plant Ecology Phase I Report*.* Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 Vol.	1982	Community structure and succession	Susitna White Paper	Alaska - Susitna	Boreal	50,764 sq km	Free-flowing	504 km	None
In 1980 and 1981 studies of the Susitna River, vegetation cover types were mapped and described for the Susitna River drainage after Viereck and Dyrness (1980). The study area included the floodplain from Talkeetna upstream to the upper Susitna River drainage as well as transmission corridors. Plant species composition and community structure were described and vegetation succession was predicted. Quantitative sampling was completed in several areas along the river to fully describe vegetation cover estimates. At least 255 vascular plan species were identified in the upper Susitna River basin. Sequences of vegetation succession and changes to vegetation from the proposed project were predicted for the Susitna River. Losses of vegetation /habitat types were predicted for the proposed dam and access route construction activities.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Uunila, L.S. 1997. Effects of river ice on bank morphology and riparian vegetation along Peace River, Clayhurst to Fort Vermillion. Ninth Workshop on the Hydraulics of Ice Covered Rivers. Committee on River Ice Processes and the Environment. Fredericton, New Brunswick, Canada, September 24-26, 1997.	1997	Ice Effects	Conference Paper	Peace River, British Columbia and Alberta, Canada	Boreal	324,000 sq km	Hydroelectric	655 km	None
Uunila (1997) assessed the allogenic effects of ice disturbance in changed hydro-regimes relating the rate of the channel adjustments longitudinally and the succession of riparian vegetation. Both the direct physical effects of ice and the indirect effects of ice jamming are investigated. The study includes the use of ice scar dating. Both botanical and geomorphic evidence suggest the frequency and magnitude of high stages peak in confined and sinuous areas with a large number of mid-channel islands. The majority of riparian vegetation damage is in shrub communities below floodplain elevation. Documentation of ice scars occurring from 0 – 1.4 m above stage were observed. The process by which a stream bank is eroded clean tended to occur around sites of ice jamming. Due to the regulated nature of the river, freeze-up and mid-winter stages may in fact have more significance than break-up.									
Uunila, Lars and Michael Church. Ice on Peace River: Effects on Bank Morphology and Riparian Vegetation. In The regulation of Peace River. ms. Edited by Michael Church. In preparation.	In Review	Dam Effects of Ice Processes	Chapter in Book	Peace River	Boreal		hydroelectric		Ice processes, riparian vegetation, sediment, flood
Uunila and Church analyze the effects of ice on the bank morphology and riparian vegetation on the regulated Peace River. Through extensive field observations and literature review, the effects of ice on Peace River are summarized. The three objectives of this study include, mapping the incidence and severity of ice jams, documenting ice-induced morphological and sedimentary features along channel margins and determine if there is an effect on channel-conveyance and channel-scale morphology, and characterizing riparian vegetation response to ice jams with emphasis on modifying the successional trend for a regulated boreal river. Results indicate that ice remains a primary factor in modifying local morphology and ice-induced flooding still creates the highest water stages on the river. Some presented results include a changed ice regime near the dam, a relatively unchanged regime below the Smokey River confluence, and the development of an ice-induced "inner shelf" 1 to 2 meters below the mature floodplain.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Vadnais, Marie-Ève, Ali A. Assani, Raphaëlle Landry, Denis Leroux, and Denis Gratton. 2012. Analysis of the effects of human activities on the hydromorphological evolution channel of the Saint-Maurice River downstream from La Gabelle dam (Québec, Canada). Geomorphology 175-176: 199-208.	2012	Dam effects on hydrology and geomorphology	Peer reviewed Basic Research	Saint-Maurice River in Québec, Canada	Boreal	43,000 km^2	hydroelectric		Seasonal flows, Bankfull width, Islets, Dams, Statistical analysis, Saint-Maurice River
Vadnais et al. (2012) analyze the hydrologic and geomorphic impacts of the Saint-Maurice River due to flow regulation from the La Gabelle dam. The morphological evolution of the Saint-Maurice River is compared to its largest unregulated tributary in order to constrain the effects of regulation. Hydrological effects of regulation were quantified by three methodologies. Morphological variability was assessed through aerial photograph comparison, and the spatiotemporal variability of the hydrologic and morphologic data was calculated by the Lombard Method. Hydrologically, results show a decrease in fall, spring, and summer maximum discharge and a significant increase in winter specific discharge. These hydrological modifications are explored further within the paper. Morphologically, two shifts in mean width were observed. The aerial photograph comparison revealed a lack of significant change over time. The morphological evolution of bankfull width downstream from La Gabelle dam was found to be different than typical literature predictions. For example, due to a decrease in morphogenic floods with a reduced sediment load downstream of dams, literature predicts a decrease in channel bankfull width. On the Saint-Maurice River however, no significant change in channel bankfull width is observed despite the reduction of the most highly morphogenic flows. The study concluded morphological evolution in a dam complex system has no cumulative effect on river reaches downstream of regulation in Québec.									
Walker, L.R. and F.S. Chapin III. 1986. Physiological controls over seedling growth in primary succession on an Alaskan floodplain. Ecology 67(6): 1508-1523.	1986	Succession and Competition vs. Facilitative Interaction	Peer Reviewed Basic Research	Alaska-Tanana	Boreal	113,959 sq km	Free-flowing	940 km	Alaska; Alnus; competition; facilitation; floodplain; nitrogen; *Picea*; *Populus*; *Salix*; succession
Walker and Chapin (1986) used a variety of field and greenhouse experiments on willow, alder, poplar and spruce trees in various plant communities at different successional stages: vegetated-silt, willow, alder, poplar, and spruce to determine the competitive or facilitative interactions between species and succession under different treatments including: shade, fertilizer, and control. Their findings point to a facilitative effect of alder in that alder soil positively affected growth of transplanted alder and poplar seedlings in absence of competition in the greenhouse. However, in the field greater inhibitory effects were observed with alder reducing growth of alder and poplar seedlings in alder communities versus vegetated-silt communities. This was the first experimental demonstration of competitive inhibition by a nitrogen fixer in primary succession. The authors discussed how alder could potentially inhibit seedling establishment via reducing light intensity, increasing root competition and water stress, and potential allelopathy. Finally, they discussed how observed growth patterns of these four plant types explain the successional pattern observed on the Tanana River floodplain.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Walker, L.R. and R. del Moral. 2008. Transition dynamics in succession: implications for rates, trajectories and restoration. In K. Suding and R.J. Hobbs, editors. New Models for Ecosystem Dynamics and Restoration. Island Press, Washington, D.C.	2008	Disturbance and Succession	Book Chapter						Succession, restoration
Walker and del Moral (2008) describe the successional patterns of ecosystems in general terms, bringing to light five models of transition dynamics. The models are developed in an earlier chapter applied to succession in this chapter. The models include 1) threshold models, 2) alternative stable states, 3) slow-fast cycles, 4) gradual continuous models, and 5) stochastic dynamics. Disturbance dynamics initiate and control successional trajectories, where there are autogenic and allogenic forms of disturbance. It is the process of disturbance in differing forms of frequency and severity that promote ecosystem stability or transition. Disturbance is patchy, and the effects can allow for communities of different seres to exist on the landscape. The subsequent rates of succession are then responses to disturbance, and are controlled by abiotic and biotic factors of the plant community. Successful restoration establishes diverse communities that are dynamically responsive to a variable climate, which requires an understanding of disturbance and an awareness of likely successional trajectories.									
Walker, L.R., J.C. Zasada, and F.S. Chapin III. 1986. The role of life history processes in primary succession on an Alaskan floodplain. Ecology 67(5): 1243–1253.	1986	Succession	Peer Reviewed Basic Research	Interior Alaska - Tanana	Boreal	113,959 sq km	free-flowing	940 km	Alaska; boreal; facilitation; floodplain; germination; herbivory; life history traits; seed bank; seed rain; succession
Walker et al. (1986) explore life history traits (seed rain, seedling establishment, and longevity) of dominant floodplain plant species (*Salix alaxensis, Alnus tenuifolia, Populus balsamifera,* and *Picea glauca*) to explain patterns of succession along the Tanana River floodplain. Based on seeding experiments and observations of natural seed establishment, they find that colonization is dependent upon interactions between stochastic events and life history traits of the dominant species. They describe observations of typical successional stages from initial depositional bar colonization by *Salix* spp. and *Equisetum* spp. through forest dominated by spruce. Experiments included a seed rain study, seed bank analysis, a seed sowing experiment on artificially cleared bare mineral plots under canopy, transect surveys to estimate seedling density, and determination of stand age. They found that seed rain varies annually in terms of seed quantity and quality, particularly for alder and spruce. They challenge classical theory that early successional species facilitate species replacement in this system and instead find that there was nearly simultaneous colonization by willow, alder, poplar, and spruce. Successful dominance based on species longevity results in successive dominance and then decline, first, of the short- lived, rapid-growing willow and alder, followed by poplar, and finally the long-lived, more slowly growing spruce.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
White, Kathleen D and Johnnie N Moore. 2002. Impacts of Dam Removal on Riverine Ice Regime. Journal of Cold Regions Engineering: 2-16.	2002	Ice Processes	Peer reviewed Basic Research	Israel River, New Hampshire; Salmon River, Connecticut; Kennebec River, Maine; Clark Fork River, Montana	temperate		hydroelectric		Dams; Ice; Cold regions; Rivers.
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. White and Moore (2002) offer insight into evaluating ice-regimes with particular focus on changing ice-regimes due to dam removal and present case studies of rivers that required ice control structures post dam-removal. Two areas of interest include the potential for increased frequency and magnitude of ice jams downstream from previous dam sites due to changed hydraulic conditions and potential increased mobilization downstream of reservoir-stored contaminated sediments. Dam removal was found to increase the frequency and severity of breakup ice jams on the Israel River while it resulted in the formation of freezeup ice jams on the Kennebec River. Guidelines including required data collection efforts are provided to assess potential adverse changes to a river's ice regime post dam removal.									
Whiting, P.J. 2002. Streamflow necessary for environmental maintenance. Annual Review of Earth and Planetary Sciences 30: 181-206.	2002	Environmental maintenance flows	Literature Reviews						channel maintenance, flushing flows, instream flow, water rights claims, habitat
Whiting (2002) describes the various environmental maintenance flows that should be considered and utilized for rehabilitation of dammed river systems. Flows for maintenance of recreation and activities, sediment size on the river bed and sediment mobility, channel morphology, channel longitudinal connectivity, river features and associated habitat, the floodplain, the hyporheic zone, and riparian vegetation are discussed. Whiting discusses the importance of maintaining each component and its interactions with other parts of the riverine system and also what methods have been used for evaluating what types of flow should be used to maintain each component. The importance of riparian vegetation for instance lies in its ability to provide shade and cover, energy inputs for the stream, buffer nutrient availability, provide habitat for invertebrates and wildlife, stabilize the river bank, and contribute woody debris and thus influence river topography. Several studies have investigated the effects of inundation duration and flows needed to sustain riparian vegetation and most have concluded that a variety of flows are required based on the species and types of vegetation present. Finally Whiting presented the issues inherent in implementing environmental maintenance flows, like the need to consider that all river systems are not the same and each channel type should be considered independently, the need to determine what types of features and habitats should be managed for (perhaps not those formed by extreme events), and the need to consider the timing and duration of flows required, the ramping rate of flows, conflicts between other water users, conflicts and interactions between other maintenance flows, and the administration of complex maintenance flows. Overall Whiting suggests attempting to copy the natural flow patterns for environmental maintenance flows.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Williams, C.A. and D.J. Cooper. 2005. Mechanisms of riparian cottonwood decline along regulated rivers. Ecosystems 8: 382-395.	2005	Cottonwood Forest Health Related to Hydro-regulation	Peer Reviewed Basic Research	Yampa and Green River, Colorado, USA	Arid and Semi-Arid		Free Flowing and Regulated, respectively		riparian; cottonwood; water relations- ; river regulation; structural adjustments; root dieback; canopy dieback.
Williams and Cooper (2005) use extensive literature citations and a case study along the Yampa and Green Rivers in Colorado to address the characteristics of river regulation that may be responsible for cottonwood dieback and death along many large rivers. A comparison within paired watershed was made on the effect to physiology of cottonwoods from river regulation. It was found the cottonwoods under the regulated conditions had 10-30% lower leaf area, 40% lower root density, and 25% less root biomass than the unregulated reach – there was also more dead limbs in the regulated reach. There was no significant difference between xylem pressure and stomatal conductance between the regulated and unregulated sites. The reduction in the biomass is hypothesized to have occurred due to a physiological response from a loss of peak flows, and a lower unsaturated zone soil water availability – these physiological adjustments have been made to ensure leaf level characteristics are unadjusted as seen in the similarities of xylem pressure and stomatal conductance. Another hypothesis about the reduced biomass and dead limbs is during the closure of the dam the reduced flows lead to severe stress and this resulted in a reduction of biomass to the regulated reach. As an interesting side note: little effect was seen in the response of floodplain-soil water from precipitation.									
Williams, G.P. and M.G. Wolman. 1984. Downstream Effects of Dams on Alluvial Rivers. Geological Survey Professional Paper 1286.	1984	Geomorphic response to dams	Literature Review	western U.S.	semiarid	varies	varies		dam effects, channel change
Williams and Wolman (1984) synthesize data on channel forming processes, sediment transport, and vegetation changes below 21 dams on alluvial rivers in semi-arid Western U.S. Using case studies of many different dams, they describe empirical trends of responses to dam construction including adjustments to channel width and bed elevation. They selected 21 dammed alluvial bed streams with repeated cross-section surveys at fixed locations before and after dam construction. Downstream effects of dam construction were seen in timing and magnitude of downstream channel adjustments to channel morphology (width, bed degradation), but viability of downstream response between systems was high. Many factors such as vegetation and bedrock constraints control river responses to dams.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Wuebben, James L., Steven F. Daly, Kathleen D. White, John J. Gagnon, Jean-Claude Tatinclaux, and Jon E. Zufelt. 1995. Ice Impacts on Flow Along the Missouri River. U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory, Special Report 95-13.	1995	Ice Impacts on Flow	White-paper report	Missouri River	temperate		multiple hydroelectric dams		Ice processes
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Wuebben et al. (1995) study the effects of ice on the Missouri River in an effort to understand varying flow distribution along the river during the ice season. The study includes analysis of ice and discharge data, statistical analysis of weather data, statistical analysis of ice-impact discharge data and correlation of ice-impacted discharge and river stages. Lastly, the study outlines methods for flow releases at Gavins Point Dam in winter in order to meet downstream water supply and maintain upstream reservoir supply.									
Yang, Daqing, Baisheng Ye, and Alexander I Shiklomanov. 2004. Discharge Characteristics and Changes over the Ob River Watershed in Siberia. Journal of Hydrometeorology 5, no. 4: 595	2004	Dam effect on hydrologic regime	White-paper report	Ob River Watershed in Siberia	Boreal	2,975,000 km^2	1 large reservoir and 3 power plants	3650 km	None
Yang et al. (2004) evaluates changes to the hydrologic regime of the Ob River due to natural variations at seasonal and regional scales and variations due to regulation by dams and reservoirs through analysis of long-term monthly and yearly discharge records over various portions of the watershed. The intent of the study is to identify streamflow variation caused by anthropogenic factors versus environmental factors and quantify impacts of observed changes. Further, the interaction of climate and hydrology in boreal regions is evaluated. Results reveal different changes in streamflow for the upper and lower parts of the watershed. These changes are in part due to flow regulation of the Ob River however analysis also lends insight into the future trends of changing hydrology in this northern watershed due to climatic changes.									

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Yang, Daqing, Douglas L. Kane, Larry D. Hinzman, Xuebin Zhang, Tingjun Zhang, and Hengchun Ye. 2002. Siberian Lena River hydrologic regime and recent change. Journal of Geophysical Research 107, No. D23, 4694.	2002	Lena River hydrologic regime	Peer reviewed Basic Research	Lena River, Siberia	Boreal	2,430,000 km^2	reservoirs	4,400 km	hydrologic regime, climate change, Lena River
While the subject of this paper is not specified as the effect of river regulation on a component of river ecology, the paper was selected as a reference in order to provide a theoretical or empirical foundation that lends context to the discussion on the downstream effects of dams. Papers were selected for one or both of two reasons: (1) it furthers the understanding of components that make up a river ecosystem more generally or (2) the study takes place on a river that experiences an ice season and provides context of a river ecosystem functioning in a northern region. Yang et al. (2002) evaluate the Lena River hydrologic regime over the 20th century through analysis of monthly records of temperature, precipitation, streamflow, river ice thickness, and active layer depth. The study was intended to identify the causes of recent change in the hydrologic regime through statistical approaches. Results found changes in the regime to primarily be caused by recent climate warming in Siberia. This was evidenced by increases in streamflow and decreases in river ice thickness during the cold season (October through April) as well as an earlier snowmelt season. Warmer winters resulted in higher permafrost temperatures and subsequent delayed freezing of the deeper active layer which increased groundwater storage thereby increasing winter streamflow. Increases in precipitation in May and June were found to cause increased streamflow in July and August. Precipitation positively correlated with a 0-2 month lag in streamflow during the summer months. Precipitation during the winter months (i.e., winter snow cover accumulation, earlier spring snowmelt, and peak flow recession) was also found to influence summer streamflow. To further understand land-atmosphere interaction and feedback, the study recommends a coupled regional climatic-hydrologic model.									
Yanosky, T.M. and R.D. Jarrett. 2002. Dendrochronologic evidence for the frequency and magnitude of paleofloods. In P.K. House, R.H. Webb, V.R. Baker, and D.R. Levish, editors. Ancient Floods, Modern Hazards. American Geophysical Union, Washington, D.C.	2002	Dendrochronology and Floods	Book Chapter	Throughout the US, Buffalo Creek, Colorado, USA	Semi-Arid			8 km reach on Buffalo Creek	Paleohydrology, Floods
Yanosky and Jarrett (2002) describe the types of botanical evidence that are most useful in dating past flood events along rivers. Tree rings are often used to precisely age trees and tree stands. Flooding often leads to a mixed age forest with the oldest trees the same age, the age and form of extant trees can be used to determine the year of flooding in addition to lending information to determine flood velocity and magnitude. Sprouts from flood damaged trees of differential growth on the top and bottom sides of trees tilted by flooding can also be used to date floods. Scars from flooding are caused by impact or over time via continuous rubbing, and a count of the number of rings between the healed scar and the outermost ring can provide an exact date of scarring and thereby flooding. The maximum height of scars can also provide a reliable estimate of flood stage. Abnormal anatomical growth of vessels and fibers has also been used to determine flood dates although these measures are often more difficult to interpret and less precise, although easier to detect, than small tree scars. Finally the authors note that the age and species of riparian trees are the limiting factors in recovering past flood information, since floods destroy evidence of earlier floods and the presence of trees with a flood record is controlled by chance mortality and the maximum tree lifespan.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Yarie, J. 2008. Effects of moisture limitation on tree growth in upland and floodplain forest ecosystems in interior Alaska. Forest Ecology and Management 256(5): 1055–1063.	2008	Moisture limitation on tree growth	Peer Reviewed Basic Research	Interior Alaska	Boreal	113,959 sq km	n/a	940 km	Boreal forest, Summer drought, Tree growth, Upland, Floodplain, Picea glauca, Betula neoalaskana, *Populus tremuloides*, *P. balsamifera*
Yarie (2008) details results from a 15-year long controlled experiment to quantify the effect of simulated drought on tree growth in upland and floodplain settings along the Tanana River near Fairbanks, Alaska. This study was designed to evaluate the effect of summer throughfall on growth of trees in upland (birch/aspen plant community) and floodplain (balsam poplar/white spruce plant community) locations. Elimination of summer throughfall in upland areas did not result in a statistically significant decrease in growth in the upland sites for any species in the 5-year or 15-year time frame. Elimination of summer throughfall in the floodplain sites resulted in significant decrease in white spruce growth in all of the 5-year and total 15-year time frames. Soil moisture conditions as a function of winter snow pack, patterns of snow melt, groundwater recharge, evapotranspiration, and summer throughfall are examined through changing hydrologic regimes. The study also suggests electrical conductivity (EC, salt) may result in reduction in water uptake and tree growth in drought conditions. Study results indicate that higher levels of growth on the floodplain are a result of both ground water and summer precipitation sources of moisture. The author recommends isotope partitioning to identify critical water source(s).									
Yarie, J., L. Viereck, K. Van Cleve, and P. Adam. 1998. Flooding and ecosystem dynamics along the Tanana River. BioScience 48(9): 690-695.	1998	Floodplain Succession	Peer Reviewed Basis Research	Tanana River, Alaska, USA	Boreal	113,959 sq km	Free Flowing	940 km	Succession, flooding
Yarie et al. (1998) describe the effects of flooding on ecosystem dynamics on the Tanana River floodplain using the state-factors approach, which is introduced and then used for the Tanana River. With the state-factors approach, vegetation and soil development are viewed as a function of topography, parent material, potential flora, and additional factors – e.g., disturbance including fire and flooding. Flooding is one of the basic controls of primary succession on the Tanana River. Succession is described as suitable bars are created during flooding, which within five years willow and balsam poplar establishment is abundant, with thin-leaf alder and white spruce present. Floodplain elevation increases resulting in terraces, and the white spruce and balsam poplar prevail. At 80-100 years the white spruce replaces the poplar for dominance, which are eventually replaced by black spruce. The buried organic layer providing ideals seed-beds for white spruce is mentioned due to the accumulation of nitrogen in these less-frequently flooded floodplain surfaces.									

Citation	Year	Topic	Source Type	Location	Habitat Type	Watershed Size	Hydrologic Regime	River Length	Key words
Ye, Baisheng, Daqing Yang, and Douglas L. Kane. 2003. Changes in Lena River streamflow hydrology: Human impacts versus natural variations. Water Resources Research 39, no. 7, 1200.	2003	Hydrology	Peer reviewed Basic Research	Lena River, Siberia	Boreal	452,000 km^2	reservoirs		streamflow change, Lena River, climate impact, human influence
Ye, Yang and Kane (2003) analyzed factors of potential change in streamflow hydrology on the Lena River. Human impacts, primarily from dams and reservoirs, are evaluated in conjunction with natural climate variations in a long-term monthly discharge record analysis. Results align with general circulation model predictions as well as large-scale hydrologic model predictions and suggest that the Lena River hydrologic regime is shifting toward earlier snowmelt and higher summer discharges. The shift may in part be due to regional climate warming and permafrost degradation. Flow regulations have modified the monthly discharge regime with reduced summer flows and increased winter flows. Combined with natural variations, streamflow in the upper regions of the Lena River has significantly increased (up to 90%) monthly discharges at low-flow months and slightly increased (5-10%) monthly discharges during the high-flow months. Discharge records that evaluate observed and predicted monthly flows due to flow regulation have been found to not always represent climatic changes and a corresponding underestimation in the summer and overestimation in the winter and fall has been identified. This study illustrates the need to incorporate the effect of natural variations and human variations when predicting the hydrologic regime of a northern watershed.									