Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biogeochemical	productivity of nearshore waters was reduced during years of high discharge with greater volumes of freshwater entering the estuary	anomalously high annual discharges (defined as >20% increase compared to previous 3 year average)	Beamish, R. J., C. M. Neville, and B. L. Thomson. 1994. A relationship between Fraser River discharge and interannual production of Pacific salmon (Onchorhynchus spp.) and Pacific herring (Clupea pallasi) in the Strait of Georgia. Can J. Fish. Aquat. Sci. 51: 2843-2855.	Very high discharges and greater volumes of freshwater entering estuary increases stratification and reduces mixing between nutrient poor surface layers and nutrient rich deeper layers; surface waters support less phyto and zooplankton and therefore productivity is lower and hypothesis is that this results in the lower numbers of salmon associated with brood years during high discharges; authors documented that during periods of weak stratification, there is a significant increase in productivity following major wind events and greater mixing; mixed layer is deeper under conditions of high freshwater discharge.
Biogeochemical	reduced inputs of CPOM to river from floodplain via loss of connectivity	reduced frequency and/or magnitdue of overbank/floodplain inundating flows; changed timing of overbank flows	Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe. 2001. Salmon at the River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon. Pages 271. National Marine Fisheries Service, Seattle.	Correlated with changes in salmon productivity in estuaries
Biogeochemical	shifts in 'macrodetritus' to 'microdetritus' based food chains in estuary	reduced frequency and/or magnitude of overbank/floodplain inundating flows;changed timing of overbank flows	Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe. 2001. Salmon at the River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon. Pages 271. National Marine Fisheries Service, Seattle.	also looked at changes in variation in the flow regime - low frequency variations suppressed; high frequency accentuated; but no clear links to effects
Biogeochemical	litter decomposition rate declines	reduction in magnitude and frequency of flooding; annual floods occurring under natural regime are eliminated	Ellis, L. M., M. C. Molles, and C. S. Crawford. 1999. Influence of experimental flooding on litter dynamics in a Rio Grande riparian forest, New Mexico. Restoration Ecology 7: 193-204.	Reduction in magnitude and frequency of annual flooding was related to a decline in litter decomposition rates on floodplain; affecting rates of nutrient cycling and potentially productivity on floodplain.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biogeochemical	reduced standing stocks of leaf litter on floodplain during autumn	increas in frequency and magnitude of floods during autumn; change in timing of floods during year, reduced winter/spring flooding and increased autumn floods	Glazebrook, H. S., and A. I. Robertson. 1999. The effect of flooding and flood timing on leaf litter breakdown rates and nutrient dynamics in a river red gum (Eucalyptus camaldulensis) forest. Australian Journal of Ecology 24: 625-635.	Leaf litter decomposition more rapid in flooded than non-flooded areas; leaf litter standing stocks typically higher in autumn when floodplain was not usually flooded - these nutrients become available to support macrophyte and biofilm production during winter and spring following natural cycle of flooding and decomposition of leaf litter on floodplain. Natural flow regime had lower frequency and magnitude of floods during autumn; increase in floods in late summer and autumn is predicted to reduce standing stocks - tested effects of flooding on litter decomposition rates; modeled effects on standing stocks with increasd autumn flooding; likely change in timing of availability of nutrients on the floodplain.
Biogeochemical	restoring connectivity between floodplain and river doubled the estimated total export of non-refractory POM from floodplain to river	reduced magnitude of flows, reduced frequency and duration of overbank flooding	Hein, T., C. Baranyi, G. J. Herndl, W. Wanek, and F. Schiemer. 2003. Allochthonous and autochthonous particulate organic matter in floodplains of the River Danube: the importance of hydrlogical connectivity. Freshwater Biology 48: 220-232.	Due to reductions in flows and especially flood flows from water management, as well as construction of levees, most of floodplain is typically disconnected from river. 2 floodplain sites were contrasted; one disconnected by regulation and one connected by restoration; river water is dominated by non-living, detrital POM; floodplain sites dominated by living, plankton POM; plankton POM is more labile and has higher nutrient content (lower C:N ratio) than detrital/terrestrial POM; when connectivity is lost, plankton production in floodplain may decrease because river--suplied nutrients are no long available from flood pulse and export of labile POM from floodplain to river (which is significant supporty for riverine food webs) no longer occurs due to absence of flood pulse.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biogeochemical	altered timing of litter inputs to river from floodplain; reduced litter inputs to river from floodplain	reduced frequency of spring floods (annual peak flows); increased frequency of small to medium floods in summer; altered timing of seasonal floods	Robertson, A. I., P. Bacon, and G. Heagney. 2001. The responses of floodplain primary production to flood frequency and timing. Journal of Applied Ecology 38: 126-136.	Murray-Darling River, Australia. River red gum forests; natural flow regime has annual spring floodplain-inundating flows in most years with a summer drought period. River red gum litter is significant component of aquatic food chains; red gums drop leaves during summer droughts; leaves are carried to river during next spring's floods. Altered flow regime results in reduced spring flooding, and presumably reduced capacity to transport litter to river. More frequent flooding in summer reduces the effect of summer droughts and in some years red gums do not drop leaves during summer.
Biogeochemical	rates of exchange of DOC, algal biomass and CPOM from floodplain to river	frequency of floodplain inundating flows	Tockner, K., D. Pennetzdorfer, N. Reiner, F. Schiemer, and J. V. Ward. 1999. Hydrological connectivity and the exchange of organic matter and nutrients in a dynamic river-floodplain system (Danube, Austria). Freshwater Biology 41: 521-535.	Danube River; floodplain is net exporter of algal biomass; DOC, and CPOM to river; export does not occur or occurs at greatly reduced rates under reduced frequencies of floodplain inundating flows
Biological - Individual - Fish	reduced salmon growth rates in estuaries	reduced frequency and/or mag of overbank/floodplain inundating flowstiming of overbank flows	Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe. 2001. Salmon at the River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon. Pages 271. National Marine Fisheries Service, Seattle.	correlation with changes in frequency and mag of overbank flows - hypothesized link to loss of connectivity and access to off-channel habitats in estuary
Biological - Individual - Fish	reduced juvenile salmon growth rates	reduced frequency and/or magnitude of overbank flows; loss of connectivity between river and floodplain	Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe. 2001. Salmon at the River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon. Pages 271. National Marine Fisheries Service, Seattle.	reduced growth rates of salmon in estuaries related to reduced overbank flows and loss of connectivity
Biological - Individual - Fish	displacement of young fish	increased velocity at higher discharge	Elwood and Waters 1969	Young trout displaced downstream; force young trout into suboptimal habitats - I.e., with higher energy costs or lower food availability. No direct tests of flow (?), but hypothesized mechanism for negative effects of high flows on trout larvae/fry
Biological - Individual - Fish	physical displacement of small fish	increased velocity at higher discharge	Heggenes, J., and T. Traaen. 1988. Downstream migration and critical water velocities in stream channels for fry of four salmonid species. Journal of Fish. Biology 32: 717-727.	Larvae entering free feeding stage are sensitive to water velocities; cannot resist velocities of >25 cm/sec. Sensitivity of larvae declines as they grow, but can still only resist velocities <50 cm/sec after two months

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Individual - Fish	reduced growth of Atlantic salmon parr during years of high peak spring floods	magnitude of spring peak flows	Jensen, A. J., and B. O. Johnsen. 1999. The functional relationship between peak spring floods and survival and growth of juvenile Atlantic salmon (Salmo salar) and brown trout (Salmo trutta). Funct. Ecol. 13: 778-785.	Compared effects of high spring floods on survival and growth of Atlantic salmon and Brown trout fry on emergence in Norwegian rivers. Mortality of salmon alevin and emerging fry increased in years with high discharge and growth was reduced in years with high discharge. For 1-year old fish or older, the size of the spring peak flood did not affect mortality.
Biological - Individual - Fish	loss of cues for spawning and/or migration	changed timing of rising flows	Lowe-McConnell, R. H. 1985. Ecological studies in tropical fish communities. Cambridge University Press, Cambridge, 302 pp.; ; Nesler, T. P., R. T. Muth, and A. F. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. Transactions of the American Fisheries Society Symposium 5: 68-79.; King, J. M., J. A. Cambray, and D. N. Impson. 1998. Linked effects of dam-released floods and water temperature on spawning of Clanwilliam yellowfish Barbus capensis. Hydrobiologia 384: 245-265.	Several species (e.g., Colorado squawfish) rely on flow spikes; peak flows or rising flows as spawning cues; reductions in peak flows due to storage behind dams and/or changed timing of flow spikes associated with irrigation releases or hydropower peaking could prevent or delay spawning and potentially affect spawning success and population persistence.
Biological - Individual - Fish	reduced spawning and recruitment success in riverine fish	timing (aseasonal) of spates; seasonal low-flows are required for spawning	Milton, D. A., and A. H. Arthington. 1983. Reproduction and growth of *Craterocephalus marjoriae* and *C. stercusmuscarum* (Pisces: Atherinidae) in south-eastern Queensland, Australia. Freshwater Biology 13: 589-597; Milton, D. A., and A. H. Arthington. 1984. Reproductive strategy and growth of the crimson-spotted rainbow fish, Melanotaenia splendida fluviatilis (Castelnau) (Pisces: Melanotaeniidae) in south-eastern Queensland, Australia. Australian Journal Marine and Freshwater Research 35:75-83; Humphries, P., and P. S. Lake. 2000. Fish larvae and the management of regulated rivers. Regulated Rivers: Research and Management 16: 421-432.	
Biological - Individual - Fish	reduced juvenile salmon overwinter survival	reduced frequency and/or magnitude of overbank flows; loss of connectivity between river and floodplain	Peterson, N. P., and L. M. Reid. 1984. Wall-base channels: their evolution, distribution, and use by juvenile coho salmon in the Clearwater River, Washington. Pages 215-226 in J. M. W. a. D. B. Houston, ed. Olympic Wild Fish Conference, Port Angeles, Washington.	reduced survival in wall-base channels related to reduced overbank flows and loss of connectivity
Biological - Individual - Fish	delayed spawning in fish	modified temperatures below dams (and when groundwater inputs have been changed?)	Zhong, Y., and G. Power. 1996. Environmental impacts of hydroelectric projects on fish resources in China. Regulated Rivers: Research and Management 12: 81-98.	
Biological - Individual - Macroinvertebrates	reduced synchrony of breeding in gammarid shrimps	reduced seasonality (I.e., reduced variability between seasons; increased flow stability)	Bunn, S. E. 1988. Life histories of some benthic invertebrates from streams of the northern jarrah forest. Australian Journal of Marine and Freshwater Research 39: 785-804.	
Biological - Individual - Macroinvertebrates	reduced survivorship of larval atyid shrumbps following early summer spates	timing (aseasonal) of spates	Hancock, M. A., and S. E. Bunn. 1997. Population dynamics and life history of Paratya australiensis Kemp, 1917 (Decapoda: Atyidae) in upland rainforest streams, south-east Queensland. Marine and Freshwater Research 48: 61-369.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Individual - Macroinvertebrates	decreased emergence; decreased survival of stoneflies with long larval development times (autumn/winter)	increased short-term fluctuations in flows	Henricson, J., and K. Muller. 1979. Stream regulation in Sweden with some examples from Central Europe. Pages 183-200 in, J. V. Ward and J. A. Stanford (eds.), The Ecology of Regulated Streams. Plenum Press, New York.	
Biological - Individual - Macroinvertebrates	increased drift of periphyton-associated macroinvertebrates with increased flow rates in New Zealand rivers	magnitude of flow rates; rate of change of flow rates	Irvine, J. R., and P. R. Henriques. 1984. A preliminary investigation on effects of fluctuating flows on invertebrates. New Zealand Journal of Marine and Freshwater Research 18: 283-290.	Rates of flow change did not affect densities of drifting inverts; all flow rates tested did result in an increase in densities of drifting inverts (chironomids, oligochaetes, trichopterans) compared to days of stable flows; drift of non-invert organic matter (periphyton) showed similar response - so inverts that drifted were probably associated with periphyton drifting inverts - i.e., effects of increased flow rates varies among assemblages of inverts and taxa associated with periphyton may be more likely to enter drift with increased flows.
Biological - Individual - Macroinvertebrates	delayed/disrupted insect emergence patterns and/or timing	modified temperatures below dams (and when groundwater inputs have been changed?)	Ward, J. V. and J. A. Stanford. 1982. Thermal responses in the evolutionary ecology of aquatic insects. Annual Review of Entomology 27: 97-117.	
Biological - Individual - Plants	reduced aquatic macrophyte growth rates and seedling survival	increased rates of water level fluctuation	Blanch, S. J., G. G. Ganf, and K. F. Walker. 1999. Tolerance of riverine plants to flooding and exposure indicated by water regime. Regulated Rivers: Research and Management 15: 43-62; Blanch, S. J., K. F. Walker, and G. G. Ganf. 2000. Water regimes and littoral plants in four weir pools of the River Murray, Australia. Regulated Rivers: Research and Management 16: 445-456.; Rea, N., and G. G. Ganf. 1994. Water depth changes and biomass allocation in two contrasting macrophytes. Australian Journal of Marine and Freshwater Research 45: 1459-1468.	Increased rate and amplitude of water level fluctuations, esp. during low flow periods decreased growth rates and seedling germination and survival of aquatic macrophytes.
Biological - Individual - Plants	reduced plant growth rates; morphological changes, increase mortality; physiological stress	duration; prolonged low flows	Reily, P. W., and P. W. Johnson. 1982. The effects of altered hydrologic regime on tree growth along the Missouri River in North Dakota. Canadian Journal of Botany 60: 2410-2423.; Perkins et al. 1984; Kondolf and Curry 1986; Stromberg, J. C., and D. Patten. 1992. Mortality and age of black cottonwood stands along diverted and undiverted streams in the eastern nevada , CA. Madrono 39: 20-223.; Rood, S., J. Mahoney, D. Reid, and L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Canadian Journal of Botany 73: 1250-1260.	
Biological - Individual - Plants	increased growth rate of river red gum (annual increase in ring width); change in timing of leaf drop	increased frequency of small and medium sized floods during summer	Robertson, A. I., P. Bacon, and G. Heagney. 2001. The responses of floodplain primary production to flood frequency and timing. Journal of Applied Ecology 38: 126-136.	Under natural flow regime no floods occur during summer drought; river regulation and irrigation return flows have increased flows to floodplain during summer resulting in increased tree growth and delay in timing of leaf drop.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Individual - Plants	reduced survival of cottonwoods	reduction in annual mean discharge resulting in lowered water tables in floodplain	Segelquist, C. A., M. L. Scott, and G. T. Auble. 1993. Establishment of Populus deltoides under simulated alluvial groundwater declines. American Midland Naturalist 130: 274-285.	Groundwater depths in semi-arid riparian areas are related to stream flows and flooding of riparian zone, so this is an indirect effect of alterations to flow regimes
Biological - Individual - Plants	physiological shift in riparian plants - zone of water uptake changes	reduced stream flows	Smith, S., B. A. Wellington, J. Nachlinger, and C. Fox. 1991. Functional Responses of Riparian Vegetation to streamflow diversion in the eastern sierra nevada. Ecological Applications 1: 89-97.	riparian trees shifted from use of groundwater to soil moisture or surface runoff as stream flows were reduced; because some plants can shift where they take up water but others can't, this would affect distribution of species, competitive interactions, species composition of communities
Biological - Individual - Plants	reduction in leaf area index, basal area and 'riparian strip width'	reduction flow volumes during growing season	Stromberg, J. C. 1993. Instream flow models for mixed deciduous riparian vegetation within a semiarid region. Regulated Rivers: Research and Management 8: 225-235.	Both the extent of riparian vegetation (width of forested riparian area) and individual measures of growth (LAI, BA) were reduced when summer flows were reduced. Reduced growth rates may be associated with lowered survival and reduction in the area occupied by riparian trees.
Biological - Individual - Plants	Plant growth measures (leaf area index, basal area, canopy height) and physiological measures (plant water potential) were negatively related to depth to groundwater	Depth to groundwater as correlated with annual discharge; mag and duration of peak flows	Stromberg, J. C. 1993. Instream flow models for mixed deciduous riparian vegetation within a semiarid region. Regulated Rivers: Research and Management 8: 225-235.	Groundwater depths in semi-arid riparian areas are related to stream flows and flooding of riparian zone, so this is an indirect effect of alterations to flow regimes
Biological - Individual - Plants	change in plant phenology; shift in main growth period for black cottonwood from May to July/August to correspond to higher water availability	timing of high flows	Stromberg, J., and D. Patten. 1990. Riparian Vegetation Instream Flow Requirements : A case study from a diverted stream in the eastern sierra nevada, ca, usa. Environmental Management 14: 185-194.	Stream diversion not only reduced stream flows, but also changed the timing of the highest flows so that riparian plant species shifted their period of greatest growth to match the timing of the highest flows.
Biological - Individual - Plants	growth rates of black cottonwood positively related to annual flow volume	volume of stream flow during current year; changed timing of high flows	Stromberg, J., and D. Patten. 1990. Riparian Vegetation Instream Flow Requirements : A case study from a diverted stream in the eastern sierra nevada, ca, usa. Environmental Management 14: 185-194.	Effects of stream flow were studied on diverted and undiverted reaches in the Sierra Nevada. Stream flow volume during the current year explained 60% of the variation in ring widths; a four- to five-fold increase in flow resulted in a doubling of the annual ring width. Adding stream flow during previous year and annual precipitation increased amount of variation in ring widths explained to 71%

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population - Fish	reduced survival of coho and chinook smolts entering Straight of Georgia and abundance of subsequent year-classes	anomalously high annual discharges (defined as >20% increased compared to previous 3 year average)	Beamish, R. J., C. M. Neville, and B. L. Thomson. 1994. A relationship between Fraser River discharge and interannual production of Pacific salmon (Onchorhynchus spp.) and Pacific herring (Clupea pallasi) in the Strait of Georgia. Can L. Fish. Aquat. Sci. 51: 2843-2855.	Correlation between years of anomalously high discharges and subsequent year-class strength from catch data; brood years that went to sea during years of very high discharges were never associated with higher index of production; very high discharges increase stratification and reduce mixing, therefore lowering productivity and probably salmon survival due to lower food resources.
Biological - Population - Fish	density of juvenile/larval fish in river	timing/mag/duration of floodplain inundating flows	Copp, G. H. 1989. The habitat diversity and fish reproductive function of floodplain ecosystems. Environmental Biology of Fishes 26: 1-26.	Mississippi River: highest densities (and diversity?) of young fish occurs downstream of where backwater channels enter river; fish biomass entering river from floodplains during wet season constitutes large portion of river's fish biomass.
Biological - Population - Fish	0+ and 1+ stages were negatively affected by summer drought	summer drought; timing of low flows	Elliott, J. M., M. A. Hurley, and J. A. Elliott. 1997. Variable effects of droughts on the density of a sea-trout, Salmo trutta population over 30 years. J. Appl. Ecol. 34: 1229-1238.	0+ and 1+ life stages were more sensitive than other life stages; all life stages were evaluated; used Ricker stock-recruitment model and found that outliers generally corresponded to years that experienced a summer drought (Black Brows Beck)
Biological - Population - Fish	no effect on 0+ trout (80-100 mm) survival	large flood' six months after emergence	Hayes, J. W. 1995. Spatial and temporal variation in the relative density and size of juvenile brown trout in the Kakanui River, North Otago, New Zealand. New Zealand Journal of Marine and Freshwater Research 29: 393-407.	New Zealand; effects of high discharges/velocity dependent on size/age-class of fish
Biological - Population - Fish	Negative effect on survival of alevin and emerging trout/salmon fry	spring high flows?	Jensen, A. J., and B. O. Johnsen. 1999. The functional relationship between peak spring floods and survival and growth of juvenile Atlantic salmon (Salmo salar) and brown trout (Salmo trutta). Funct. Ecol. 13: 778-785.	Tested in two Norwegian rivers; mortality was increased in years with high discharge during spring peak flows.
Biological - Population - Fish	abundance of age-0 fish in annual collections (long term catch data set); positive correlations between abundance of native species and max stage and duration of major floods; negative correlations with min stage, numbers of reversals and count of major floods; non-native species showed opposite pattern	reversals in water surface elevation; maximum stage levels; length of spring flood	Koel, T. M., and R. E. Sparks. 2002. Historical patterns of river stage and fish communities as criteria for operations of dams on the Illinois River. River Research and Applications 18: 3-19.	Illinois River; comparison of interannual variation in fisheries catch data with variability in 33 hydrologic parameters (IHA parameters) - primarily variability in stage, flood and recession duration; frequency, timing, and rate of change in water levels. Native species abundances were most closely correlated with the more natural flow regime while non-native species were correlated with more altered regimes

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population - Fish	reduced abundance of salmonid species	increase in frequency of peak flows; 10 yr floods are now 1-4 yr floods	Moscrip, A. L., and D. R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Puget Lowland streams. J. of the American Water Resources Association 33: 1289-1297.	Comparison of small number of urbanized and non-urbanized (much lower degree of urbanization) streams basins in Puget Sound; over time period in which urbanization occurred there was a change in freq of peak flows in urbanized streams; not in controls; also over same time period, decline in abundance of salmon in urbanized streams but not in controls. Hypothesized mechanisms - increase in depth of redd scour, displacement of LWD due to increased velocities.
Biological - Population - Fish	decreased egg survival	high discharges	Sear, D. A. 1993. Fine sediment infiltration into gravel spawning beds within a regulated river experiencing floods: ecological implications for salmonids. Regul. Rivers 8: 373-390.	fine sediment filling in over redds; decrease in intragravel O2 content
Biological - Population/Community - Amphibians	decline in abundance of frogs and decline in species richness in floodplain wetlands (Australia)	changed timing of flooding (winter/spring to summer/autumn); increased magnitude of summer flows; change in floodplain flood regime	Healey, M., D. Thompson, and A. Robertson. 1997. Amphibian communities associated with billabong habitats on the Murrumbidgee floodplain, Australia. Australian Journal of Ecology 22: 270-278.	Not a direct test of flow effects. River regulation has resulted in floodplain wetlands changing from ephemeral, seasonally flooded, largely fishless wetlands to permanently inundated billabongs with abundant exotic fish species. Includes discussion of predation effects of exotic fish on native frog species and influence of changes in flood timing and frequency associated with the change from fishless to with fish billabongs.
Biological - Population/Community - Aquatic Species	relative fish species abundance (biomass); periphyton community classification (filamentous green vs. diatom); benthic invertebrate dominant taxa (mayflies/stoneflies 'clean river'; vs. oligochaetes/chironomids)	CVFLOW (coefficient of variation of flow); CVMAF (cv of mean annual max flow); CVMALF (cv of mean annual low flow); MAF (mean of annual max flow); MALF (mean of annual low flow); MEANF (mean annual flow); MEDIANF (median annual flow - exceeded 50% of time); RUNOFF (mean annual flow divided by catchment area (in metres))	Jowett, I. G., and M. J. Duncan. 1990. Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. New Zealand Journal of Marine and Freshwater Research 24: 305-317.	Relative measures of flow variability in New Zealand rivers; rainbow trout were more abundant in rivers with low variability; periphyton dominated by filamentous green algae were associated with high flow variability; 'clean river' invertebrate taxa were associated with rivers with low flow variability; mean velocities decreased as flow variability increased (i.e., low variability rivers had higher mean velocities, esp. at low flows)

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Birds	community composition shifted in relation to degree of river regulation and change in inundation regime of associated wetlands	increased frequency of summer flooding and magnitude of summer flows resulting in change from ephemeral, seaonally flooded to permanently inundated wetlands on floodplain	Briggs, S. V., S. A. Thornton, and W. G. Lawler. 1997. Relationships between hydrological control of river red gum wetlands and waterbird breeding. EMU 97: 31-42.	Breeding waterbirds were more abundant and there were more species at wetlands with no or slight hydrological control than in heavily controlled wetlands. Precocial waterbirds in particular did not breed in wetlands with controlled water regimes (i.e., permanently flooded and rapidly fluctuating); hypothesis is that macrophyte abundance and invertebrate production is lower when shallow, temporarily flooded wetlands are replaced by permanently flooded or widely fluctuating water levels. Altricial birds bred in controlled wetlands, but breeding will probably not conitnue in these areas if permanent inundation kills trees. Natural flood regime has been replaced by higher summer discharge (some due to irrigation return flows) and more frequent periods of summer flooding as rivers are regulated to provide irrigation flows.
Biological - Population/Community - Birds	reduced waterbird species richness; reduced abundance	reduced frequency, duration and area of inundation of flooplain wetlands/off-channel habitat	Kingsford, R. T., and R. F. Thomas. 1995. The Macquarie Marshes in arid Australia and their waterbirds: a 50-year history of decline. Environmental Management 19: 867-878.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Birds	riparian bird abundance and species richness greater in temporary wetlands than permanently inundated floodplain wetlands	natural flood regime maintains range of wetland conditions from permanently flooded to ephemeral	Parkinson, A., R. M. Nally, and G. P. Quinn. 2002. Differential macrohabitat use by birds on the unregulated Ovens River floodplain of southeastern Australia. River Research and Applications 18: 495-506.	Not a direct test of flow effects. On the unregulated Ovens River, floodplain wetlands range from permanently inundated billabongs (oxbow lakes) to temporarily inundated, ephemeral wetlands. The presence of the full range of wetland types likely contributes to species richness and abundance of floodplain birds (macrohabitat heterogeneity increases species richness). Temporary wetlands were utilized more by aquatic birds than billabongs were in this study. Shallow waters of temporary wetlands had greater cover of macrophytes, direct and indirect (macroinvertebrates) source of food for aquatic birds. Cycle of alternate wetting and drying of temporary wetlands may also result in greater litter decomposition and greater availability of nutrients - greater productivity of aquatic invertebrates. River regulation that reduces floodplain inundation and/or increases water level stability (changes ephemeral wetlands to permanent wetlands) may result in reduced floodplain and riparian bird abundance and species richness.
Biological - Population/Community - Fish	increased abundance/dominance of exotic fish species	conversion of lotic to lentic habitats (impoundments, reductions in mean annual or base flows)	Arthington, A. H. and D. R. Bluhdorn. 1994. Distribution, genetics, ecology and status of the introduced cichlid, Oreochromis mossambicus, in Australia. Pages 53-62 in D. Dudgeon and P. Lam (eds.), Inland waters of tropical Asia and Australia: Conservation and management. Mitteilungen, Internationale Vereiningung fur Theoretishce und Angewandte Limnologiae 24 Stuttgart.	
Biological - Population/Community - Fish	fish assemblages were significantly different between regulated and unregulated sites and differences were correlated with changes in seasonal availability and persistence of key habitat types (I.e., shallow and slow-water habitats)	hydropower peaking flows; highly fluctuating daily flows; daily peak flows typically about 660% of the minimum flow	Bowen, Z. H., M. C. Freeman, and K. D. Bovee. 1998. Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes. Transaction of the American Fisheries Society 127: 455-468.	Hydropeaking operation of dams on regulated rivers resulted in greatly fluctuating daily flows and reduced the availability and persistence of shallow and slow-water habitats; abundance of catostomids was correlated with availability and persistence of these habitats in spring (typical habitats in unregulated rivers); catostomids are major faunal component of these sytems.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	percentage of non-native fish was related to river mile and mean April/May flow in the previous year	mean flows during spring (April/May)	Brown, L. R., and T. Ford. 2002. Effects of flow in the fish communities of a regulated California river: implications for managing native fishes. River Research and Applications 18: 331-342.	Juveniles were sampled in spring and fish community composition (percentage non-native species) was related to river mile (longitudinal location) and mean April/May flows in the sampling year and mean April/May flows the previous year. Authors conclude that differential spawning success of native and non-native species the previous spring was responsible for differences in species assemblages during the sampling year. Native fish in Tuolumne spawn earlier in the year at cooler water temperatures than non-natives; higher flows are correlated with lower temperatures, so higher flows and cooler temperatures create better spawning conditions for natives than low flows and warmer temperatures. Natural flow regimes have high winter/spring discharges; these flows favor native species which are predominantly riffle spawners; non-native species tend to spawn in lower velocity, bottom areas.
Biological - Population/Community - Fish	range expansions/contractions; change in distribution of species	interbasin water transfers	Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.	
Biological - Population/Community - Fish	change in distribution of parasitic/disease vectors (potential change in biotic interactions)	interbasin water transfers	Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.	
Biological - Population/Community - Fish	loss of fish adpated to turbid habitats	conversion of lotic to lentic habitats (impoundment, reduction in flows)	Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.	
Biological - Population/Community - Fish	decline in population densities of riverine crayfish and snails	conversion of lotic to lentic habitats (impoundment, reduction in flows)	Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.	
Biological - Population/Community - Fish	reduced areas for spawning and/or recruitment success for lowland river fish	reduced frequency, duration and area of inundation of flooplain wetlands/off-channel habitat	Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	Density of 0+ fish was strongly and negatively related to discharge rate during the emergence period; the higher the discharge during emergence, the lower the 0+ fish densities. 69% of overall variability and 16.6 % of within reach variability in 0+ densities explained by Q10.	discharge rate; Q10 (daily discharge exceeded 10% of the time during the season divided by the interannual median discharge); timing, magnitude, duration and rates of change of flows were assessed	Cattaneo, F., N. Lamouroux, P. Breil, and H. Capra. 2002. The influence of hydrological and biotic processes on brown trout (Salmon trutta) population dynamics. Can.J. Fish. Aquat. Sci. 59: 12-22.	Tested relationships between hydrological variables and biological variables (density-dependent survival) on brown trout population size across 30 reaches in French streams. Looked at 13 hydrological variables that measured average, low, high flows, infrequent flow events, daily rates of change, and overall variability. Divided hydrology variables up into 'seasons' based on trout life cycle: reproduction period; emergence period; and growth period to evaluate effect of the timing of flow variables on fish.
Biological - Population/Community - Fish	Negative relationship between high discharges during spawning, emergence, and larval growth periods and arctic grayling year class strength.	timing of high stream flows…; flow regime during spawning, emergence, and larval stages	Clark, R. A. 1992. Influence of stream flows and stock size on recruitment of arctic grayling (Thymallus arcticus) in the Chena River, Alaska. Can. J. Fish. Aquat. Sci. 49: 1027-1033.	Chena River, Alaska; looked at relationship of year class strength to spawner abundance and flow regime during spawning, emergence and larval stages. No relationship found between spawner abundance and subsequent year class strengths (I.e., no stock-recruitment relationship). Arctic grayling (egg, fry, juvenile)
Biological - Population/Community - Fish	change in fish species composition, range expansion of salt tolerant species	reduce discharge due to water withdrawals	Contreras, S., and M. L. Lozano. 1994. Water, endangered fishes, and development perspectives in the arid lands of Mexico. Conservation Biology 8: 379-387.	water diversion from Rio Bravo del Norte in Mexico has resulted in: salinization of lower river; replacement of 32 native fishes adapted to freshwater with 54 marine, or highly salt-tolerant species; change in species composition; range expansion of marine fishes (as much as 40 km upstream)
Biological - Population/Community - Fish	reduction in fish population (densities? Species number?)	reduction of flow variability; reduction of peak (scouring) flows; increase in stability and magnitude of baseflows	Converse, Y. K., C. P. Hawkins, and R. A. Valdez. 1998. Habitat relationships of subadult humpback chub in the Colorado River through the Grand Canyon: spatial variability and implications for flow regulation. Regulated Rivers: Research and Management 14: 267-284.	
Biological - Population/Community - Fish	elimination of salmonid species and pelagic spawning fish; increased dominance of 'generalist' fish species	conversion of lotic to lentic habitats (impoundment, reduction in flows)	Copp, G. H. 1990. Effect of regulation on 0+ fish recruitment in the Great Ouse, a lowland river. Regulated Rivers: Research and Management 5: 151-163.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	change in reproductive timing; reduced reproductive success of prairie fishes; reduced egg survival	reduction in flood flows and flow stabilization	Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155-165 in Matthews, W. J., D. C. Heins (eds.), Community and Evolutionary Ecology of North American Stream Fishes. Norman (OK): University of Oklahoma Press. Echelle, A. A., G. R. Luttrell, R. D. Larson, A. V. Zale, W. L. Fisher, and D. M. Jr. Leslie. 1995. Decline of native prairie fishes. Pages 303-305 in LaRoe, E. T., G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac (eds.), Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. Washington (DC): US Department of the Interior, National Biological Service.	prairie fishes are adapted to spawning during floods; reduction in flood flows deposits eggs in unfavorable habitats and egg mortality due to loss of connectivity with floodplain habitats
Biological - Population/Community - Fish	negative effects of high discharges on egg and alevin survival via movement of bedload, scouring redds	high discharges	DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Can. J. Fish. Aquat. Sci. 54: 1685-1698.	Review article with numerous references for negative effects of discharge/scour on salmonids.
Biological - Population/Community - Fish	lowered productivity of estuarine fish and invertebrates; reduced biomass and growth rates of fish in estuary	flow regulation by dams; altered seasonal inflows to estuary; higher inflows of freshwater to estuary in late summer and fall	Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11: 179-190.	estuarine fish and invertebrates that normally invade Mobile river delta wetlands with intruding salt water (presumably during late summer and fall - natural flow regime had lowest flows during fall); altered timing of salt water intrusion alters timing of use of estuary by these species and affects productivity of estuary
Biological - Population/Community - Fish	changes in relative availability and/or persistence of different habitat types (shallow-slow; shallow-fast; deep-fast) among seasons between regulated and unregulated reaches	increase in flow fluctuations due to hydropeaking (esp. in summer); decrease in median spring and summer flows in regulated reaches compared to pre-dam and unregulated reaches	Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11: 179-190.	Reductions in median flows (esp. spring) and increases in summer peak flows resulted in lower habitat persistence (I.e., lower habitat stability), esp. in spring, and changed the relative availability of habitat (relatively more shallow slow with regulation). Temporal habitat stability in the regulated reach was greatly reduced compared to the unregulated reach - esp. in spring. Habitat stability in the regulated reach was greater only during some (dry) summers when hydropower production was put on hold and flows were stabilized; persistence of shallow fast and shallow slow habitats then were similar to unregulated conditions. Persistence (stability) of habitats significantly affects fish abundances and community structure independently of habitat availability!!

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	inter-annual variability in reproductive success (juvenile production) related to flow variability; recruitment success differs among species each year resulting in more diverse fish assemblages	increase in flow fluctuations due to hydropeaking (esp. in summer); decrease in median spring and summer flows in regulated reaches compared to pre-dam and unregulated reaches	Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11: 179-190.; Sparks 1995; Walker and Thoms 1993	Reductions in median flows (esp. spring) and increases in summer peak flows resulted in lower habitat persistence (I.e., lower habitat stability), esp. in spring, and changed the relative availability of habitat (relatively more shallow slow with regulation). Temporal habitat stability in the regulated reach was greatly reduced compared to the unregulated reach - esp. in spring. Habitat stability in the regulated reach was greater only during some (dry) summers when hydropower production was put on hold and flows were stabilized; persistence of shallow fast and shallow slow habitats then were similar to unregulated conditions. Persistence (stability) of habitats significantly affects fish abundances and community structure independently of habitat availability!!
Biological - Population/Community - Fish	negative correlation between YOY abundances and availability of shallow-fast habitats and with summer peak flows - I.e., stable low flows are necessary for survival of some fish species native to river	increase in flow fluctuations due to hydropeaking (esp. in summer); decrease in median spring and summer flows in regulated reaches compared to pre-dam and unregulated reaches	Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11: 179-190.; Sparks, R. E. 1995. Need for ecosystem management of large rivers and floodplains. BioScience 45: 168-182.	Reductions in median flows (esp. spring) and increases in summer peak flows resulted in lower habitat persistence (I.e., lower habitat stability), esp. in spring, and changed the relative availability of habitat (relatively more shallow slow with regulation). Temporal habitat stability in the regulated reach was greatly reduced compared to the unregulated reach - esp. in spring. Habitat stability in the regulated reach was greater only during some (dry) summers when hydropower production was put on hold and flows were stabilized; persistence of shallow fast and shallow slow habitats then were similar to unregulated conditions. Persistence (stability) of habitats significantly affects fish abundances and community structure independently of habitat availability!!

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	changes in relative abundance of fish species (YOY); changes in relative abundance of spring vs. summer spawning species; spring spawning species were less abundant in flow-regulated reach; regulated river was dominated by fish that can extend spawning to summer months	increase in flow fluctuations due to hydropeaking (esp. in summer); decrease in median spring and summer flows in regulated reaches compared to pre-dam and unregulated reaches	Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11: 179-190; Freeman, M. C., Z. H. Bowen, and J. H. Crance. 1997. Transferability of habitat suitability criteria for fishes in warm-water streams. North American Journal of Fisheries Management 17: 20-31.	Natural flow variability in these streams results in inter-annual variability in the availability of habitat types. In low flow summers (low precip) there is high availability of shallow water habitats; in high-flow summers there is more deep (fast-) water habitats. Flow regulation (hydropower dams) resulted in lower median flows - spring flows were always lower than the median pre-dam spring flow; summer flows were <97% of pre-dam summer flows - except in summers with very high rainfall, summer flows in the regulated reach approximated the pre-dam summer flows. Summer flows in the regulated reaches are also highly variability due to hydropeaking. Stable low-flow conditions following spawning have been correlated with increased juvenile abundances of subsets of species within river assemblages. Trait most clearly associated with ability to tolerate the increased flow fluctuation and reduced median flows due to hydropeaking is a prolonged reproductive seaons (i.e., extending into July or later)
Biological - Population/Community - Fish	native fish species populations showed negative response to flow regulation	flow regulation by dams and irrigation diversion; most frequently reduced seasonal flooding and increased baseflows during drought seasons	Gehrke, P. C., and J. H. Harris. 2001. Regional-scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. Regulated Rivers Research and Management 17: 369-391.	Using 40 rivers in SE Australia, comparison of regulated and unregulated rivers and relative abundances of native and non-native fish species. Regulated and unregulated rivers had significantly different fish communities, even though regional characteristics were retained. Proportion of native species in total catch was greater in unregulated river than in regulated rivers, more native species showed negative population responses to flow regulation than non-native species did. Species richness was not affected by flow regulation, maybe because non-native species replaced native species; this study used proportion of native fish in a community as a more sensitive measure of community change than species richness alone. No alien fish species showed only negative responses to flow regulation; alien fish either had positive responses or mixed responses.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	increased invasion of non-native fish species	elimination/reduction of flow variability; increased seasonal stability (I.e., decreased variability between seasons)	Gehrke, P. C., K. L. Astles, and J. H. Harris. 1999. Within-catchment effects of flow alteration on fish assemblages in the Hawkesbury-Nepean River system, Australia. Regulated Rivers: Research and Management 15: 181-198; Walker, K. F., A. J. Boulton, M. C. Thoms, and F. Sheldon. 1994. Effects of water-level changes induced by weirs on the distribution of littoral plants along the River Murray, South Australia. Australian Journal of Marine and Freshwater Research 45: 1421-1438.	
Biological - Population/Community - Fish	changes in species composition, species abundances, species ranges	change in magnitude, frequency and timing of floodplain inundating flows due to dams changes in extent, duration, frequency and timing of floodplain inundation and lateral/longitudinal connections for fish migration	Goulding, m., J. J. H. Smith, and D.J. Mahar. 1996. Floods of Fortune: Ecology and Economy along the Amazon. New York: Columbia University Press; Barthem, R. B., and M. C. Lambert de Brito Ribeiro 1991. Life strategies of some long-distance migratory catfish in relation to hydroelectric dams in the Amazon basin. Biological Conservation 55: 339-345; Ribeiro, M. C. L. B., M. Petrere, and A. A. Juras. 1995. Ecological integrity and fisheries ecology of the Araguaia-Tocantins river basin Brazil. Regulated Rivers: Research and Management 11: 325-350.	Amazon; other Latin American systems; lots of evidence that these systems are characterized by highly migratory fish fauna that utilizes flooded floodplains extensively for feeding, rearing, breeding; some evidence that alterations to floodplain inundation due to dams has affected abundance and ranges of some species and affected overall productivity and species compositions - little information on species-specific alterations or how timing of events in particular affects individual species; also, little information on how alteration to flooding affects floodplain productivity and hence indirectly affects fish growth and reproduction
Biological - Population/Community - Fish	49% reduction in fish species diversity; above dam 50% reduction in diversity; reductions in fish abundance	reduction in flow due to dams results in reduction/loss of river-floodplain connection;	Goulding, m., J. J. H. Smith, and D.J. Mahar. 1996. Floods of Fortune: Ecology and Economy along the Amazon. New York: Columbia University Press; Barthem, R. B., and M. C. Lambert de Brito Ribeiro 1991. Life strategies of some long-distance migratory catfish in relation to hydroelectric dams in the Amazon basin. Biological Conservation 55: 339-345; Ribeiro, M. C. L. B., M. Petrere, and A. A. Juras. 1995. Ecological integrity and fisheries ecology of the Araguaia-Tocantins river basin Brazil. Regulated Rivers: Research and Management 11: 325-350.	hypothesized mechanisms: changes to downstream movement of eggs; upstream migration of adults; change in longitudinal connectivity due to migration barriers speculated to affect species populations via fragmentation and effects on metapopulation dynamics
Biological - Population/Community - Fish	declines in abundance where connectivity between channel and floodplain has been lost or reduced	alteration of annual flood regimes; elimination of floodplain and/or inundated off-channel habitats by elimination/reduction in flood flows	Guillory, V. 1979. Utilization of an inundated floodplain by Mississippi River fishes. Biological Sciences 42: 222-228.	several references cited that demonstrate use of off-channel flooded habitats for feeding and reproduction by fish typically found in main channel; species that could potentially be affected by loss of connectivity and flooding of floodplain habitats and/or by change in timing of flooding; fishery catches have declined in areas where annual flood regimes have been altered.
Biological - Population/Community - Fish	shift in abundance to small, short-lived species with extended spawning seasons (up to 9 months) in regulated compared to unregulated rivers	reduced duration of high winter flows; increased magnitude of summer flows (irrigation)	Humphries, P., L. G. Serafini, and A. J. King. 2002. River regulation and fish larvae: variation through space and time. Freshwater Biology 47: 1307-1331.	Highly regulated compared to 'mildly' regulated lowland rivers in Australia; highly regulated river had fewer species, and was dominated by two small, short-lived species with extended spawning periods.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	reduction in abundance, population decline of American shad	reduced flows (plus dams) resulting in barriers to spawning migration; loss of longitudinal connectivity	Jenkins, R. E. and N. M. Burkhead. 1994. Freshwater Fishes of Virginia. Bethesda (MD): American Fisheries Society.	commerical landings of shad have declined over 90% in past 100 years, 'blockage of spawning runs by dams a major contributing factor'
Biological - Population/Community - Fish	abundances of many small-bodied fishes that use shallow water habitats are reduced in flow-regulated systems with hydropeaking	increased flow fluctuations; reduced stability of shallow-water habitats	Kinsolving, A., D., and M. B. Bain. 1993. Fish assemblage recovery along a riverine disturbance gradient. Ecological Applications 3: 531-544.	the small-bodied fishes that persist in hydropeaking systems seem to be those that can spawn during the summer - abundances of these species are correlated with persistence of shallow water habitats in summer - stable flow periods during summer facilitate survival of these species in flow-regulated systems; thermal regimes are important in influencing reproductive timing and thermal regimes may be affected by regulation and hydropeaking, water temperatures affected by regulation may be important as well
Biological - Population/Community - Fish	reduced egg survival; with floods of <10 yr recurrence, probability of egg clutch scour was 5%; with 1 in 100 yr floods, probability was 20%	frequent floods (<10 yr recurrence)	Lapointe, M., B. Eaton, S. Driscoll, and C. Latulippe. 2000. Modelling the probability of salmonid egg pocket scour due to floods. Canadian Journal of Fisheries and Aquatic Science 57: 1120-1130.	Conclusion was that for many salmonids, high frequency flood events (<10 yr recurrence int) did not have a significant effect on egg survival via scour; larger floods did had significant effects.
Biological - Population/Community - Fish	1+ trout densities negatively affected by high flows	30 day maximum flow	Latterell, J. J., K. D. Fausch, C. Gowan, and S. C. Riley. 1998. Relationship of trout recruitment to snowmelt runoff flows and adult trout abundance in six Colorado mountain streams. Rivers 6: 240-250.	Relationship tested in 6 Colorado streams; strong relationship found between 30 day maximum flow and 1+ densities; however, the amount of variation explained by flow variable was not given; flow magnitude was tested by not flow timing
Biological - Population/Community - Fish	abundances of juvenile (age-1) trout declined with increases in mean 30-day maximum streamflow in previous year	increases in 30-day maximum flows	Latterell, J. J., K. D. Fausch, C. Gowan, and S. C. Riley. 1998. Relationship of trout recruitment to snowmelt runoff flows and adult trout abundance in six Colorado mountain streams. Rivers 6: 240-250.	Abundance of juvenile trout were negatively related to mean 30-day max flows the previous year, significantly but more weakly related to annual maximum flows and frequency of high flows the previous year. Abundance of age-1 trout was also negatively related to abundance of adult trout the previous year (when recruits were age-0), so that displacement of fry by high snowmelt runoff is general mechanism limiting trout recruitment in western U.S. mountain streams, but density-dependent effects of adult trout also limit trout populations.
Biological - Population/Community - Fish	negative correlation between stream flows and 1+ trout survival; no relation with 0+ trout survival	winter stream flow volumes	Mesick, C. F. 1995. Response of brown trout to streamflow, temperature, and habitat restoration in a degraded stream. Rivers 5: 75-95.	contradicts results that smaller size/age-classes are more vulnerable to high flows

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	population declines, extinction of two taxa	water diversions - reduced flows and dams are migration barriers	Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries 14(6): 22-38.	lake suckers are greatly imperiled in western NA because migration between lakes and streams has been eliminated in many areas by dams and/or water diversion
Biological - Population/Community - Fish	population decline and fragmentation (white sturgeon in PNW)	migration barriers, reduced habitat area due to low flows	Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries 14(6): 22-38.	abundance of white sturgeon in PNW, North America
Biological - Population/Community - Fish	change in fish species composition; loss of salmon species, retention of cutthroat	increase in freuqency of peak flows; 10 yr floods are now 1-4 yr floods	Moscrip, A. L., and D. R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Puget Lowland streams. J. of the American Water Resources Association 33: 1289-1297.	Comparison of small number of urbanized and non-urbanized (much lower degree of urbanization) streams basins in Puget Sound; over time period in which urbanization occurred there was a change in freq of peak flows in urbanized streams; not in controls; also over same time period, decline in abundance of salmon in urbanized streams but not in controls. Hypothesized mechanisms - increase in depth of redd scour, which would affect fall spawning salmonids more than spring spawning trout.
Biological - Population/Community - Fish	population decline of delta smelt and other native delta species	reduced discharge of freshwater into San Francisco Bay (water diversion)	Moyle, P. B. , B. Herbold, D. E. Stevens, and L. W. Miller. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin estuary, California. Transactions of the American Fisheries Society 121: 67-77.	reduction in freshwater inflows has moved mixing zone out of shallow embayments and into deeper channels which are less favorable habitat for delta smelt and other species that congregate near the shore
Biological - Population/Community - Fish	Negative relationship between discharge and fish density	mean monthly discharge	Nehring, R. B., and M. A. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the physical habitat simulation system. Rivers 4: 1-19.	Tested on salmonids in 11 Colorado streams
Biological - Population/Community - Fish	Negative effect of high spring flows and emerging fry; population bottleneck due to this effect	high spring flows	Nehring, R. B., and M. A. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the physical habitat simulation system. Rivers 4: 1-19.	Tested on salmonids in 11 Colorado streams
Biological - Population/Community - Fish	Negative relationship between discharge and fish population densities	mean monthly discharge?	Nuhfer, A. J., J. R. D. Clark, and G. R. Alexander. 1994. Recruitment of brown trout in the south branch of the Au Sable river, Michigan in relation to streamflow and winter severity. Fisheries Research Report 2006 Michigan Department of Natural Resources Fisheries Division, Lansing, MI.	Tested in a Michigan stream

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	decline in abundance of native fish in downstream reaches in CO river correlated with decreased food resource availability (periphyton/benthic macroinvertebrate production), increases in fine sediment, and decreased frequency of floods that flush fine sediments from riffles	decrease in frequency of spring snowmelt floods in regulated CO river; spring floods occur less frequently after regulation; the period between sediment flusing flows has increased 2X to 5X in study reaches; downstream riffles have greater amounts of sediment accumulation than upstream riffles	Osmundson, D. B., R. J. Ryel, V. L. Lamarra, and J. Pitlick. 2002. Flow sediment-biota relations: implications for river regulation effects on native fish abundance. Ecological Applications 12: 1719-1739.	Spring snowmelt floods in unregulated CO river were sufficient to mobilize bed and flush silts and sands from coarser substrates; frequency of these floods has deceased with regulation resulting in increased duration of periods for sediment accumulation between these floods of 2X to 5X greater than historical conditions. Downstream reaches have more fine sediment, less biotic production (periphyton/benthic inverts) and fewer CO pikeminnow (a piscivore). Authors conclude that reduced productivity has affected abundance of prey for pikeminnow and may explain its decline in downstream reaches. Decline in productivity attributed to decrease in spring flood frequency and accumulations of fine sediment in riffles.
Biological - Population/Community - Fish	population decline of native fish; altered instream habitat	stabilization of flows; reduction of sediment loads	Pfleiger, W. L., and T. B. Grace. 1987. Changes in the fish fauna of the lower Missouri River, 1940-1983. Pages 166-177 in W. J. M. a. D. C. Heins, ed. Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, Oklahoma; Hesse, L. W., G. E. Mestl, and J. W. Robinson. 1993. Status of selected fishes in teh Missouri River in Nebraska with recommendations for their recovery. Pages 327-340 in L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, ed. Restoration Planning for the Rivers of the Mississippi River Ecosystem. U. S. Department of the Interior, National Biological Survey, Washington D.C.	Fish in prairie rivers are adapted to fluctuating flows and high turbidity; dams, levees and dikes have stabilized flows and removed sediment, altering conditions and leading to declines in native species abundance; unclear whether native species have been replaced with exotics, but it seems likely; effects of altered flows are hypothesized to be via altered food webs, altered habitat, and altered flow conditions during reproductive periods
Biological - Population/Community - Fish	reduced 0+ cyprinid and centrarchid abundances	spring floods	Schlosser, I. J., and P. J. Angermeier. 1990. The influence of environmental variability, resource abundance, and predation on juvenile cyprinid and centrarchid fishes. Pol. Arch. Hydrobiol. 37: 265-284.	Descriptive study; relationship not quantified.
Biological - Population/Community - Fish	species richness of shallow water fish was reduced in regulated reaches below dams; mostly because of a loss of riverine specialists (fluvial specialists)	decrease in peak flows; increase in daily flow fluctuations	Travnichek, V. H., and M. J. Maceina. 1994. Comparison of flow regulation effects on fish assemblages in shallow and deep water habitats in the Tallapoosa River, Alabama. Journal of Freshwater Ecology 9: 207-216.	shallow water species richness and diversity were more affected by flow regulation that deep water species
Biological - Population/Community - Fish	relative increase in abundance of habitat generalists (Centrarchids) and decrease in fluvial specialists (Catostomids) in both shallow water and deep water habitats with flow regulation below dams in the Tallapoosa	daily flow fluctuations related to hydropeaking	Travnichek, V. H., and M. J. Maceina. 1994. Comparison of flow regulation effects on fish assemblages in shallow and deep water habitats in the Tallapoosa River, Alabama. Journal of Freshwater Ecology 9: 207-216.	number of species, Shanon's diversity index and species abundances were compared

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Fish	shift in recruitment from floodplain spawners to in-channel spawners	rapid fall rate; rapid pulse recession	Welcomme, R. L. 1989. Review of the present state of knowledge of fish stocks and fisheries of African rivers. Canadian Special Publication of Fisheries and Aquatic Sciences 106: 515-532.	
Biological - Population/Community - Fish	metapopulation dynamics, population fragmentation, population declines	migration barriers - dams and water diversions	Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120: 98-105.	Hypothesized mechanism to explain decline of populations associated with dams. Migratory fish whose populations are isolated by dams and/or impoundments will have metapopulation dynamics and perhaps population viability affected. If isolated populations (I.e., upstream of dams) suffer catastrophic declines due to stochastic environmental effects or biological (e.g., predation) factors, then these areas cannot be re-colonized from populations downstream of dam - metapopulation stability will be affected; overall decline in population size and range constriction would be expected.
Biological - Population/Community - Fish	replacement of lotic with lentic fauna; replacement of native with non-native species	impoundment of river reaches	Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120: 98-105., Starnes 1995, Bonetto et al. 1987 (Pringle et al. 2000)	impounded reaches are lentic habitats and biota adapted to lotic systems are generally displaces; many non-native species are lentic or more tolerant species and can replace native species in these reaches; more tolerant taxa can also migrate upstream from impoundments, replacing native fish even in areas not directly impounded
Biological - Population/Community - Fish	range restrictions; population declines	barriers to migration	Wooley and Crateau 1985, Jenkins and Burkhead 1994, Lee at al. 1980, additional refs in Pringle et al. 2000	river herring, striped bass, American shad, American eel, anadromous sturgeon; all these species have declined in abundance and are absent from former ranges in areas upstream of dams; eel were once very common but are now rare - migrations between freshwater and marine are impeded by dams
Biological - Population/Community - Macroinvertebrates	zooplankton community compositon; abundance of rotifers and crustaceans in off-channel habitats	connectivity of floodplain and river; 'water age' a measure of 'lotic' character of water - river water is age 0; the lower the age the greater the connectivity with river water	Baranyi, C., T. Hein, C. Holarek, S. Keckeis, and F. Schiemer. 2002. Zooplankton biomass and community structure in a Danube River floodplain system: effects of hydrology. Freshwater Biology 47: 473-482.	Rotifers dominate community in water of low age (I.e., more lotic waters) which crustaceans gradually replace rotifers as water age increases. Maintenance of zooplankton community structure and biomass/density is related to maintenance of exchange processes between river and floodplain.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Macroinvertebrates	reduction in species richness and abundance (freshwater shrimp)	reduced flows due to water withdrawals	Benstead, J. P., J. G. March, C. M. Pringle, and F. N. Scatena. 1999. Effects of a low head dam and water abstraction on migratory tropical stream biota. Ecological Applications 9: 656-668.	high larval mortality during migration to estuaries linked to large water withdrawals (half daily amount draining national forest); is mortality due to low flows, temperature?; overall effects of larval mortality on upstream recruitment and population size not known
Biological - Population/Community - Macroinvertebrates	large increases in numbers of drifting animals; significant declines in numbers and diversity of organisms in benthic samples	increases in flow to simulate small spates	Bond, N. R., and B. J. Downes. 2003. The independent and interactive effects of fine sediment and flow on benthic invertebrate communities characteristic of small upland stream. Freshwater Biology 48: 455-465.	Experimental manipulation of flow and fine sediment in 8 artificial streams to evaluate the independent and interactive effects of sediment and flow. Increases in flow caused increases in numbers of drifting animals and decreased in numbers and diversity of animals in benthic samples; these effects were independent of sediment. Flow increases alone can affect benthic invertebrates, regardless of whether flow increases are associated with increases in bed movement or sediment. Response of organisms to flow increases, however, are likely to be affected by presence of flow refugia which affect animals' ability to escape shear forces. Response to flow was a short term response in this experiment; this experiment used moderate amounts of fine sediment, responses to massive amounts of fine sediment are likely to be significant.
Biological - Population/Community - Macroinvertebrates	diversity of carabid beetles was greater along rivers with unregulated flow regimes compared to regulated rivers; mostly because specialist species adapted to particular flooding regimes were absent from regulated rivers	reduction/elimination of spring floods; reduced frequency and duration of overbank flows and floodplain inundation	Bonn, A., K. Hagen, and D. W.-V. Reiche. 2002. The significance of flood regimes for carabid beetle and spider communities in riparian habitats - a comparison of three major rivers in Germany. River Research and Applications 18: 43-64.	Natural flooding of large river floodplains associated with un-regulated flow regimes and un-leveed floodplains had greater species richness, more specialized fauna and contained more rare and endangered species than highly regulated rivers; low-lying floodplain habitats that are frequently inundated by river floods are important habitats for conservation of carabid beetles and spiders.
Biological - Population/Community - Macroinvertebrates	stranding of macroinvertebrates	Rapidly fluctuating flows below dams; increased number of reversals (daily); increased variability (daily) in flows	Bradford 1997; Bradford et al. 1995; (cited in Bunn and Arthington 2002)	
Biological - Population/Community - Macroinvertebrates	increase in abundance of larval blackfies (insects of lentic habitats)	reduction of flow variability; reduction of peak (scouring) flows; increase in stability and magnitude of baseflows	Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Macroinvertebrates	reduction in species richness of benthic macroinvertebrates	Rapidly fluctuating flows below dams; increased number of reversals (daily); increased variability (daily) in flows	Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.	
Biological - Population/Community - Macroinvertebrates	mussel population size and distribution	inundation of main channel shoals - changed water depths due to dam	Burkhead, N. M., S. J. Wash, B. J. Freeman, and J. D. Williams. 1997. Status and restoration of the Etoway River, an imperiled southern Appalachian ecosystem. Pages 375-444 in Benz, G. W., and D. E. Collins (eds.), Aquatic Fauna in Peril: The Southeastern Perspective. Decatur (GA): Lenz Design and Communications, Southeast Aquatic Research Institute Special Publication 1.	southeastern U.S. - Coosa River, Etoway River, Mobile river basin - large losses of native mussel fauna (67% in impounded river sections Tombigbee, almost complete extipation in Etowah, almost complete loss of Coosa river mollusk fauna
Biological - Population/Community - Macroinvertebrates	species extinction? (grazers)	fluctuating flows (daily alternation of dessication and inundation of algal biofilms)	Burns, A., and K. F. Walker. 2000. Effects of water level regulation on algal biofilms in the River Murray, South Australia. Regulated Rivers Research and Management 16: 433-444.	Some species of snails have gone extinct in Murray-Darling system; correlations with highly fluctuating flow regime - speculation that mechanism is fluctuating flows result in dominance of algal biofilms by dessication tolerant taxa (filamentous Chlorophytes) that is not adequate food source for grazers
Biological - Population/Community - Macroinvertebrates	benthic species richness, biomass, density were negatively and positively related to flood frequency; response of periphyton and invertebrates differed	FRE3 (flood frequency - flood is flows higher than 3X the median flow) best overall flow variable; flood frequency variables in general were correlated with biota	Clausen, B., and B. J. F. Biggs. 1997. Relationships between benthic biota and hydrological indices in New Zealand streams. Freshwater Biology 38: 327-342.	Purpose of study was to find ecologically meaningful hydrological indices for New Zealand streams. Thirty-four hydrological variables were related to 6 measures of benthic community attributes (biomass, density, richness of algae and macroinvertebrates). Average flow conditions and variability were significantly related to most biological variables. FRE3 (frequency of floods greater than 3X the median flow) was determined to be most useful overall indicator - periphyton biomass decreased with increasing FRE3, invertebrate density went up initially and then declined with increasing FRE3, periphyton richness and diversity decreased with increasing FRE3. Flood frequency measures were the best overall ecologically useful flow variable in New Zealand streams; explained significant amount of variance in 4 of 6 benthic community measures.
Biological - Population/Community - Macroinvertebrates	change in functional groups - reduction in shredders and increase in filter feeders	reduction in flow variability - constant flow regime	Cortes, R. M. V., M. T. Ferrerira, S. V. Oliveira, and D. Oliveira. 2002. Macroinvertebrate community structure in a regulated river segment with different flow conditions. River Research and Applications 18: 367-382.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Macroinvertebrates	community composition was changed under conditions of prolonged summer low flows and/or droughts	mean summer low flows, median summer low flows, duration of summer low flows	Extence, C. A., D. M. Balbi, and R. P. Chadd. 1999. River flow indexing using British benthic macroinvertebrates: a framework for setting hydroecological objectives. Regulated Rivers: Research and Management 15: 543-574.	Evaluated macroinvertebrate data for a series of English streams (chalk, granite, sandstone) to determine if LIFE scores (Lotic-invertebrate Index for Flow Evaluation) could be correlated with any of a set of flow statistics describing stream hydrology. LIFE scores were derived from flow associations (literature/BPJ) and relative abundances. Flow statisitcs were mean, max, min, median, percentiles, etc. for different time periods (year, summer season, running summer mean - RSM) and flow statistics were used with measures of flow duration and flow period to assess relationships between LIFE scores and flow flow variables. Summer flows were most strongly correlated with LIFE scores, especially RSM of different durations for summer season, esp. for chalk streams. Decreased relative abundance of taxa associated with fast flowing water was related to prolonged minimum flow periods. Single flow variables frequently accounted for most of ecological variation, but combinations of flow variables sometimes increased amount of variation explained and may suggest flow targets for specific rivers or
Biological - Population/Community - Macroinvertebrates	life cycles of macroinvertebrates; abundance of macroinvertebrates	timing of spring floods, magnitude of spring floods is related to degree and timing of connection between channel and floodplain marshes	Hart, D. D., and C. M. Finelli. 1999. Physical-biological coupling in streams: the pervasive effects of flow on benthic organisms. Annual Review of Ecology and Systematics 30: 363-395.	Canadian river, Alberta. Mayfly life cycle is tied to connectivity between river and floodplain marshes - mayflies (nymphs) migrate upstream during first spring snowmelt floods and enter drainage channels and floopdlain marshes, there they complete life cycle over summer and adults fly to river to oviposit in fall; nymphs overwinter in river. Alteration to the timing or extent of spring flooding could affect completion of life cycle; also loss of connectivity with marshes via reductions in spring peak flows and/or draining of marshes, channelization, etc. could reduce survival of mayflies.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Macroinvertebrates	abundance and biodiversity of amphidromous shrimp in Caribbean; migration barriers	migration barriers on dams with no spillway and water abstraction - loss of longitudinal connectivity	Holmquist, J. G., J. M. Schmidt-Gengenbach, and B. B. Yoshioka. 1998. High dams and marine-freshwater linkages: effects on native and introduced fauna in the Caribbean. Conservation Biology 12: 621-630.	amphidromous freshwater shrimp (non-breeding migration between salt and freshwater) in Caribbean are eliminated in upstream reaches above dams with no spillways; abundance and richness reduced above dams with spillways; high larval motrality during downstream passage to estuaries - water intakes at dams
Biological - Population/Community - Macroinvertebrates	change in location of benthic and epibenthic invertebrates within estuary related to steepening of river delta slopes	reduction in flow - diversion of 40% of annual average runoff from basin	Jay, D. A., and C. A. Simenstad. 1996. Downstream Effects of Water Withdrawal in a Small, High-Gradient Basin: Erosion and Deposition on the Skokomish River Delta. Estuaries 19: 501-517.	Steepening of delta resulted in a change in the extent of intertidal habitat at different depths. Paper discusses effects of water diversion from Skokomish River on delta, estuary and Hood Canal; extensive logging has also occurred in the basin;comparison of pre-diversion (1885) with post-diversion (1972) delta bathymetry; hypothesized mechanism is a reduction in sediment transport capacity due to flow reduction combined with an increase in sediment supply due to logging.
Biological - Population/Community - Macroinvertebrates	Reduction in standing crop (biomass) of benthic macroinvertebrates	Rapidly fluctuating flows below dams; increased number of reversals (daily); increased variability (daily) in flows	Layzer, J. B., M. E. Gordon, and R. M. Anderson. 1993. Mussels: the forgotten fauna of regulated rivers: a case study of the Caney Fork River. Regulated Rivers: Research and Management 8: 63-71.	
Biological - Population/Community - Macroinvertebrates	oyster growth rates, vulnerability to predation, population dynamics change in response to magnitude of freshwater inputs to estuary	reduced volumes and changed timing of freshwater flows into estuary due to water diversion, water storage	Livinston, R. J., F. G. Lewis, G. C. Woodsum, X. F. Niu, B. Galperin, W. H. Christensen, M. E. Monaco, T. A. Batista, C. J. Klein, R. L. Howell, and G. L. Ray. 2000. Modelling oyster population response to variation in freshwater input. Estuar. Coastal Shelf Sci. 50: 655-672.	
Biological - Population/Community - Macroinvertebrates	reduced biomass and abundanced of aquatic insects	elimination of flooding resulting in elimination of lateral channel meandering and off-channel habitat	Mestl, G. E., and L. W. Hesse. 1993. Secondary productivity of aquatic insects in the unchannelized Missouri River, Nebraska. Pages 341-349 in L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, ed. Restoration Planning for the Rivers of the Mississippi River Ecosystem. U.S. Department of the Interior, National Biological Survey, Washington D.C.	elimination of off-channel habitat because river no longer meanders (elimination of flood flows or channel forming flows) in lower Missouri has reduced aquatic insect production by as much as 60%; indirect effect of flow; aquatic insects dependent on off-channel habitat
Biological - Population/Community - Macroinvertebrates	Relative densities of invertebrates in wetlands changed in response to different flooding regimes; ostracods adapted to colonize ephemeral wetlands were less abundant in permanently flooded systems	changed timing of flooding of riverine wetlands; changed duration of flooding - permanently flooded vs. ephemeral wetlands	Nielsen, D. L., T. J. Hillman, F. J. Smith, and R. J. Shiel. 2002. The influence of seasonality and duration of flooding on zooplankton in experimental billabongs. River Research and Applications 18: 227-237.	Results may have been affected by experimental design; no strong response of community composition to experimental treatments; speculation that some species may be lost from permanently flooded systems because triggers to emerge from resting/seed stages don't exist. Change in community structure resulted from changes in relative abundance of taxa already present; species composition did not change.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Macroinvertebrates	increased standing crop (biomass) and reduced diversity of macroinvertebrates	reduction of flow variability; reduction of peak (scouring) flows; increase in stability and magnitude of baseflows	Petts, G. E. 1984. Impounded Rivers. Perspectives for Ecological Management. John Wiley and Sons, Chichester, UK, 326-pp.	
Biological - Population/Community - Macroinvertebrates	species composition (fish, freshwater shrimps)	hydrologic alterations associated with dams and water abstraction	Pringle, C. M., and F. N. Scatena. 1999. Aquatic ecosystem deterioration in Latin America and the Caribbean. Pages 104-113 in U. a. M. E. S. Hatch, ed. Managed Ecosystems: the MesoAmerican Experience. Oxford University Press, New York.	streams in Caribbean are dominated by migratory fish and shrimps and are vulnerable to hydrological alterations that interfere with migration (barriers, altered timing of hydrologic events)
Biological - Population/Community - Macroinvertebrates	numerous fish and mussel/invertebrate responses	flow diversion, impoundments, flow alterations - mostly due to dams	Pringle, C. M., M. C. Freeman, and B. J. Freeman. 2000. Regional effects of hydrologic alterations on riverine macrobiota in the New World: tropical-temperate comparisons. BioScience 50: 807-823.	review article of temperate/tropical comparison of major types of ecological responses to flow alteration - effects on species population persistence, extinction, metapopulation dynamics, interspecific interactions, etc.
Biological - Population/Community - Macroinvertebrates	no differential response of predator and prey taxa to flood disturbance (resistance and resilience)	high flow events (above bankful); three moderate floodsof about equal discharge; one larger flood about 2X discharge of others	Thomson, J. R. 2002. The effects of hydrological disturbance on the densities of macroinvertebrate predators and their prey in a coastal stream. Freshwater Biology 47: 1333-1351.	Testing predictions that predators and prey will respond differently to flood disturbances; if predators are more resistant or resilient then increased disturbance will have a greater effect on prey taxa; if prey are more resistant or resilient, then increased disturbance will have a greater impact on predatory taxa (as in BIBI metrics - predators are expected to be less tolerant of degraded stream conditions). This study found highly variables responses of predators and prey to individual flood events. The two most flood resistant taxa were predators, but prey taxa recovered more quickly after floods, however, there were no consistent differences between trophic groups.
Biological - Population/Community - Macroinvertebrates	changed interspecific interactions; population declines in mussels; range restrictions, population extirpation	migration barriers to fish; dams and water diversions; impoundments	Williams, J. D., J. M. L. Warren, K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18: 6-22.; Watters, G. T. 1996. Small dams as barriers to freshwater mussels (Bivalvia, Unionida) and their hosts. Biological Conservation 75:: 79-85.	Freshwater mussels rely on native fish hosts to complete their life cycle; when dams, impounded river sections, and other migration barriers negatively affect the population sizes and/or movements of fish hosts, mussel populations are negatively affected. Mussels no longer have access to many portions of river systems where habitat may still be suitable, because their fish hosts can no longer reach those portions of the river. Several mussel species have been extirpated from reaches where fish hosts are no longer available.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	reduced species richness of riparian vegetation; reduced species richness of drift material (floating propagules/water dispersed propagules)	fragmentation by dams; impounded sections (lentic vs. lotic habitat); reduction in flood flows and reduction in mean annual flows	Andersson, E., C. Nilsson, and M. E. Johansson. 2000. Effects of river fragmentation on plant dispersal and riparian flora. Regulated Rivers: Research and Management 16: 83-89.	Dams are barriers to propagule dispersal; short-floating seeds in particular may sink or die before passing through open water and dams; long-floating species have greater probability of passing dams; after 30 years, floras among adjacent impounded riparian sections are different mostly because species with poor floating abilities are unevenly distributed among sites. In non-dammed rivers with longitudinal connectivity intact, floras of adjacent riparian sites are not different.
Biological - Population/Community - Plants	reduced plant diversity; reduced plant migration/dispersal	longitudinal connectivity lost through dams and flow diversions	Andersson, E., C. Nilsson, and M. E. Johansson. 2000. Effects of river fragmentation on plant dispersal and riparian flora. Regulated Rivers: Research and Management 16: 83-89.; Jansson, R., C. Nilsson, M. Dynesius, and E. Andersson. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecological Applications 10: 203-224; Jansson, R., C. Nilsson, and B. Renofalt. 2000. Fragmentation of riparian floras in rivers with multiple dams. Ecology 81: 899-903.	fragmentation; loss of connectivity
Biological - Population/Community - Plants	reduced species richness downstream of dams and/or regulated reaches with reduced flows	rivers fragmented by dams; loss of longitudinal connectivity; reduced flows and lowered velocities	Andersson, E., C. Nilsson, and M. E. Johansson. 2000. Plant dispersal boreal rivers and its relation to the riparian flora. Journal of Biogeography 27: 1096-1106.	In free-flowing rivers the species represented (presence and relative abundance) in the drifting propagules were the same as those present in the vegetation of upstream reaches; in rivers regulated by dams, the species composition of drifted propagules did not match vegetation upstream - longitudinal connections and effective dispersal (hydrochory mostly) make it possible for seeds to reach most parts of the river - riparian vegetation is homogenized; fragmentation and reduced velocities in reglated rivers result in fewer propagules reaching downstream sites from upstream vegetation. Species composition of drifted propagules was similar to that of the upstream vegetation in free-flowing rivers; on dam-regulated rivers, species composition of drifted propagules was not similar to upstream vegetation.
Biological - Population/Community - Plants	river regulation resulted in loss of species with high regeneration and/or colonizing ability in areas that are infrequently flooded (disturbed)	reduced frequency of flooding	Barrat-Segertain, m. H., C. P. Henry, and G. Bornette. 1999. Regeneration and colonization of aquatic plant fragments in relation to disturbance frequency of their habitats. Archiv fur Hydrobiologie 145: 111-127.	Rhone River; frequently flooded habitats had species with higher regeneration and colonizing abilities than habitats where flooding no longer occurs due to river regulation; results in change in life history strategy of dominant vegetation.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	successful cottonwood recruitment; peak discharges linked to successful cottonwood recruitment	reduced magnitude of peak flows; peak flows > 1850 m3/s were associated with successful cottonwood establishment & were assumed to be the minimum flows necessary for cottonwood recruitment	Bovee, K. D., and M. L. Scott. 2002. Implciations of flood pulse restoration for Populus regeneration on the upper Missouri River. River Research and Applications 18: 287-298.	Dams on the upper Missouri River have reduced/eliminated cottonwood recruitment and led to collapse of riparian forests. In Wild and Scenic reach of Missouri, dams have reduced mag of peak flow events by about 50%. By relating extent of floodplain inundation (2-d hydraulic models) with extent of cottonwood canopy using aerial photographs, estimated that flows of at least 1850 m3/s were required for cottonwood regeneration. These peak flows could be restored by changing dam operations but economic costs of increased flooding and institutional and legal inflexibilities in dam operations need to be addressed to successfully implement a flow restoration strategy in this reach. Use of flow models with flood damage curves indicate that some restoration of flows => 1850 m3/s would be possible without compromising other uses of river.
Biological - Population/Community - Plants	floodplain plant community composition - replacement of emergent grasses with trees; change in physiognomy (structure; grassland to forest) as well as life history traits (inundation/summer drought tolerant to phreatophyte)	reduction in frequency and duration of floodplain inundation (from every 3 out of 4 years to less than 2 out of 4; from 9+ months to less than 4); change in timing of flood flows (from large winter floods to small summer floods); reduced area of floodplain inundated (from 75% to 10%)	Bren, L. J. 1992. Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia. Australian Journal of Ecology 17: 395-408.	Australian low gradient floodplain at tributary junction; water diversion and irrigation return flows have changed timing and extent of floodplain inundation; native grasses replaced by river red gum forests; summer drought season low flows have been augmented, favoring less drought-tolerant woody vegetation. The percent of the floodplain inundated each year has been reduced by about 50%, increasing the extent of areas where woody vegetation may be able to establish (river red gum seedlings cannot withstand inundation for prolonged periods). The duration of flooding has been reduced by about 50%+; less flood tolerant woody vegetation is now able to invade and establish more areas of the floodplain. Again, combination of reduced flooding in winter/spring and augmented summer low flows favors woody over herbaceous vegetation. Earlier work by Bren (1988) established that river red gums require moderate flood regimes but do not exist where flood frequency is very high or very low.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	algal biofilms - biomass and species composition - no effects	highly fluctuating flows vs. stable flows (over 90 day period)	Burns, A., and K. F. Walker. 2000. Effects of water level regulation on algal biofilms in the River Murray, South Australia. Regulated Rivers Research and Management 16: 433-444.	no effect on biomass or species composition of algal biofilms under stable flows (constant water depth) and daily flow fluctuations that resulted in alternate dessication and immersion - authors speculate that because this is a highly regulated system, only tolerant taxa remain
Biological - Population/Community - Plants	increased abundance/extent of non-native plants	stabilized flow regimes	Busch, D. E. and S. D. Smith. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U. S. Ecological Monographs 65(3): 347-370. Ward, J. V. and J. A. Stanford. 1979. The ecology of regulated streams. Plenum Press, New York 358 pp.	
Biological - Population/Community - Plants	increased extent and abundance of exotic plant species in riparian vegetation	reduced frequency of flooding; changed timing of flooding; increased dry season base flows; decreased dry season base flows	Connor et al. 1981; Bren, L. J. 1992. Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia. Australian Journal of Ecology 17: 395-408.; Crivelli et al. 1995; Toner and Keddy 1997; Friedman and Auble 1999; Galat, D. L., and R. Lipkin. 2000. Restoring ecological integrity of great rivers: historical hydrographs aid in defining reference conditions for the Missouri River. Hydrobiologia 422/423: 29-48.	Bren 1988 - river red gum forests with reduced peak floods in winter/spring and increasedd summer low flows had greater number of introduced, invasive species; replacement of native species with non-natives.
Biological - Population/Community - Plants	reduced riparian plant species cover and diversity	duration; prolonged low flows	Connor et al. 1981; Bren, L. J. 1992. Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia. Australian Journal of Ecology 17: 395-408.; Crivelli et al. 1995; Toner and Keddy 1997; Friedman and Auble 1999; Galat, D. L., and R. Lipkin. 2000. Restoring ecological integrity of great rivers: historical hydrographs aid in defining reference conditions for the Missouri River. Hydrobiologia 422/423: 29-48.	Prolonged periods of low flows result in reduced cover of riparian plant species and increased cover of upland species.
Biological - Population/Community - Plants	altered riparian plant communities	duration; prolonged inundation; changed timing of seasonal inundation and low flows	Connor et al. 1981; Bren, L. J. 1992. Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia. Australian Journal of Ecology 17: 395-408.; Crivelli et al. 1995; Toner and Keddy 1997; Friedman and Auble 1999; Galat, D. L., and R. Lipkin. 2000. Restoring ecological integrity of great rivers: historical hydrographs aid in defining reference conditions for the Missouri River. Hydrobiologia 422/423: 29-48.	Following regulation of the Missouri River, the timing of growing season low flows changed so that low flows which use to occur in late summer/early fall now occur either much earlier in growing season or much later. Germination of early-successional riparian tree species is timed to occur with late summer low flows when new areas of moist soil are exposed; late summer inundation of these areas by higher summer flows prevents germination and establishment of early successional trees.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	reduced regeneration and recruitment of plants requiring periodic floodplain disturbance to regenerate	stabilized flow regimes	Fenner, P., W. W. Brady, and D. R. Patten. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. Journal of Range Management 38: 135-138.; Shankman and Drake 1990; Johnson, W. C. 1994. Woodland expansion in the Platte River, Nebraska: Patterns and causes. Ecological Monographs 64: 45-84.; Rood, S., J. Mahoney, D. Reid, and L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Canadian Journal of Botany 73: 1250-1260.; Scott et al. 1997; Cordes et al. 1997	stabilized flows reduce flooding and disturbance to floodplain; reduced nutrient inputs from river to floodplain; seed dispersal is ineffective because suitable safe sites are not available; reduced regeneration
Biological - Population/Community - Plants	expansion of forest/woody vegetation into river corridor (I.e., below formwer water line)	elimination/reduction of annual flooding	Gill, 1973; Toner and Keddy 1997; Grelsson and Nilsson 1980; Johnson, W. C. 1994. Woodland expansion in the Platte River, Nebraska: Patterns and causes. Ecological Monographs 64: 45-84. - cited in Nilsson and Svedmark 2002	
Biological - Population/Community - Plants	replacement of lotic stream habitat with more lentic habitat dominated by aquatic macrophytes (Typha) where aquatic macrophytes formerly did not exist	dry season flows changed from 4% of annual flow to 32%; ephemeral reaches become perennial	Goes, B. J. M. 2002. Effects of river regulation on aquatic macrophyte growth and floods in the Hadejia-Nguru wetlands and flow in the Yobe River, Northern Nigeria: implications for future water management. River Research and Applications 18: 81-95.	spread of aquatic macrophytes resulted in increased siltation and blocked channels; reduced downstream flows
Biological - Population/Community - Plants	reduced predictability of wetland flooding downstream of irrigation dams	reduced peak and annual flows; greater contribution of dry season flows to annual flows	Goes, B. J. M. 2002. Effects of river regulation on aquatic macrophyte growth and floods in the Hadejia-Nguru wetlands and flow in the Yobe River, Northern Nigeria: implications for future water management. River Research and Applications 18: 81-95.	reduced peak flows lead to less frequent wet season flooding of wetlands; increased dry season flows result in flooding of wetlands during what is normally the dry season when wetlands are dry; increased dry season flows have converted some parts of seasonal wetlands into permanently flooded habitats
Biological - Population/Community - Plants	washout of plants; failure of seedling establishment	rate of change; more rapid rates of rise and fall during water level fluctuations associated with dam operations (or increased flashiness of system?)	Grelsson 1986; Rood, S., J. Mahoney, D. Reid, and L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Canadian Journal of Botany 73: 1250-1260. Rood et al. 1999	
Biological - Population/Community - Plants	invasion by Russian olive/tamarix; conversion from herbaceous/emergent to woody wetland vegetation	change in timing of high flows; loss of seasonal flow peaks	Horton 1977; Friedman et al. 1998; Toner and Keddy 1997; Springer et al. 1999; Hill et al. 1998	invasion by exotics; change in vegetation structure
Biological - Population/Community - Plants	floodplain forest maintenance; plant species composition; structural diversity	floods with return interval of 1.9 years - Tana River, Kenya	Hughes, F. M. R. 1990. The influence of flooding regimes on forest distribution and composition in the Tana River floodplain, Kenya. Journal of Applied Ecology 27:475-491.	Tana River, Kenya. Floodplain forest development (tree recruitment, seedling survival, resistance to invasion by shrubs/grasses) requires floods of 1.9 yr return interval; change in frequency of this mag flood would be expected to lead to changes in floodplain vegetation community. Relationship based on determining mag and duration of floodplain inundation required for tree regeneration.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	number of plant species reduced (decline in biodiversity)	reduced current velocities and increased amount of open water habitat in regulated rivers below dams	Jansson, R., C. Nilsson, M. Dynesius, and E. Andersson. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecological Applications 10: 203-224; Jansson, R., C. Nilsson, and B. Renofalt. 2000. Fragmentation of riparian floras in rivers with multiple dams. Ecology 81: 899-903.	number of plant species in riparian vegetation was reduced because fewer species were represented in the pool of propagules that reached sites (short-floating species were eliminated)
Biological - Population/Community - Plants	porportion of short-floating species represented in riparian vegetation was reduced	reduced current velocities and increased amount of open water habitat in regulated rivers below dams	Jansson, R., C. Nilsson, M. Dynesius, and E. Andersson. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecological Applications 10: 203-224; Jansson, R., C. Nilsson, and B. Renofalt. 2000. Fragmentation of riparian floras in rivers with multiple dams. Ecology 81: 899-903.	In unregulated rivers both short-floating and long-floating seeds are well-dispersed - I.e., long-floating seeds don't seem to have an advantage in getting to most sites; when rivers are regulated with reduced velocities and more open water sections, more short-floating seeds fail to reach colonization sites (sink or die before getting to a safe site?); selection against plants with short-floating seeds (hydrochory) in local riparian flora under regulated conditions; different dispersal mechanisms may be favored under regulated vs. unregulated conditions.
Biological - Population/Community - Plants	reduced species diversity; riparian floras differ in species composition among adjacent impoundments in similar environmental settings in dammed rivers in northern Sweden	river fragmentation from dams; reduced velocities due to river regulation	Jansson, R., C. Nilsson, M. Dynesius, and E. Andersson. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecological Applications 10: 203-224; Jansson, R., C. Nilsson, and B. Renofalt. 2000. Fragmentation of riparian floras in rivers with multiple dams. Ecology 81: 899-903.	Dams are barriers to propagule dispersal; short-floating seeds in particular may sink or die before passing through open water and dams; long-floating species have greater probability of passing dams; after 30 years, floras among adjacent impounded riparian sections are different mostly because species with poor floating abilities are unevenly distributed among sites. In non-dammed rivers with longitudinal connectivity intact, floras of adjacent riparian sites are not different.
Biological - Population/Community - Plants	plant species diversity; reduction in diversity of vegetation structural types from 4 to 1 due to elimination of regeneration sites/conditions for riparian cottonwood and willow	elimination of floods above 2500 m3 sec-1;reduction in mean daily flows (by 80%)	Johnson, W. C. 1992. Dams and riparian forests: case study from the upper Missouri River. Rivers 3: 229-242.	Missouri River below Garrison Dam. Prior to damming 2/3 of peak flows were above 2500 m3 sec-1; after damming no flows were above this. Prior to damming, floodplain habitats were disturbed by high flows and vegetation reflected age of surfaces - young pioneer to mature vegetation - 4-5 habitat mosaic types by stage of vegetation. Following damming only the mature vegetation stage was represented. Patch diversity reduced and patch turnover basically eliminated in the absence of disturbance from the river.
Biological - Population/Community - Plants	reduced area and diversity of wetland vegetation	reduced frequency, duration and area of inundation of flooplain wetlands/off-channel habitat	Kingsford, R. T. 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. Austral Ecology 25:109-127.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	reduced growth and survival of native aquatic macrophytes; increased invasion of non-native species	elimination of seasonal wet-dry cycles; increased stability of water levels	Kingsford, R. T. 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. Austral Ecology 25:109-127.	
Biological - Population/Community - Plants	replacement of native cottonwood forests with russian olive-dominated forests along northern Great Plains rivers	reductions in magnitude of peak flows	Lesica, P. and S. Miles. 1999. Russian olive invasion into cottonwood forests along a regulated river in north-central Montana. Canadian Journal of Botany 77: 1077-1083.	Reductions in peak flows and/or reductions in mean flows have decreased cottonwood recruitment, decreased cottonwood survival and have resulted in non-native Russian olive replacing cottonwood along many rivers; russian olive can tolerate lower water tables, drier conditions and does not require period disturbance or specific soil moisture/rate of water table decline conditions to establish and persist. Cottonwoods can only reproduce where seasonal timing of high flows, new sediment deposition, and recession of high flows correponds to the timing of seed release and viability.
Biological - Population/Community - Plants	reduced numbers of vascular plant species in riparian zone, reduced biodiversity	rivers fragmented by dams	Nilsson, C., A. Ekblad, M. Gardfjell, and B. Carlberg. 1991. Long-term effects of river regulation on river margin vegetation. Journal of Applied Ecology 28: 963-987.	regulated rivers (by dams) had fewer vascular plant species in riparian zone than free-flowing rivers (comparison of 13 rivers in same region of northern Sweden; 9 of 13 were dams)
Biological - Population/Community - Plants	timing of seed dispersal and germination of riparian trees corresponds to timing of flood water recession (March/April) under natural flow regime	lower wet season (winter) flows and higher and stable dry season flows (spring-summer) reduce suitable germination sites for seeds	Pettit, N. E. 2000. Factors affecting the recruitment of riparian vegetation on the Ord and Blackwood Rivers in Western Australia. Edith Cowan University, Perth; Pettit, N. E., and R. H. Froend. 2001. Variability in flood disturbance and the impact on riparian tree recruitment in two contrasting river systems. Wetland Ecology and Management 9: 13-25.	Australia; riparian trees river reg gum (Eucalyptus camaldulensis) and Melalueca leucandra disperse seeds during time (March/April) when flood waters are receding and exposing bare moist, sediments. Regulated rivers have lower wet season flows and higher more constant dry season flows so that less area of bare sediment is exposed and available for germination when seeds are dispersed and/or these areas are inundated by higher dry season flows.
Biological - Population/Community - Plants	decline in forested/woody rirparian vegetation	elimination/reduction of annual flooding	Pettit, N. E. and R. H. Froend. 2000. Variability in flood disturbance and impact on riparian tree recruitment in two contrasting river systems. Wetlands Ecology and Management 9:13-25.	riparian forests typically decline in extent following elimination of annual floods in arid and/or semi-arid regions due to a combination of lack of regeneration and lowered water tables/soil moisture in riparian zone

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	species richness negatively correlated with duration of riparian zone inundation	relationship between frequency and duration of riparian inundating flows and riparian vegetaiton floristics and structure; (days riparian zone is flooded/year)	Pettit, N. E., R. H. Froend, and P. M. Davies. 2001. Identifiying the natural flow regime and the relationship with riparian vegetation for two contrasting western Australian rivers. Regulated Rivers: Research and Management 17: 201-215.	relationships found on rivers with highly predictable and strongly seasonal flow regime with low variability in monthly flows; 80% of mean discharge occurs in late winter/early spring; summer/autumn flows were less than 3% and CV of flows was high in summer; seasonality was highly predictable between years
Biological - Population/Community - Plants	% cover exotic plant species correlated with duration of flooding and number of times per year that riparian zone was inundated	increased disturbance intensity and frequency as reflected in flood frequency (number events/year) and duration (days/year) related to increased cover of exotic species	Pettit, N. E., R. H. Froend, and P. M. Davies. 2001. Identifiying the natural flow regime and the relationship with riparian vegetation for two contrasting western Australian rivers. Regulated Rivers: Research and Management 17: 201-215.	relationships found on rivers with highly predictable and strongly seasonal flow regime with low variability in monthly flows; 80% of mean discharge occurs in late winter/early spring; summer/autumn flows were less than 3% and CV of flows was high in summer; seasonality was highly predictable between years
Biological - Population/Community - Plants	% cover shrubs negatively correlated with number of events per year that inundate riparian zone	increased disturbance frequency (number of events/year) correlated with decrease in shrub cover	Pettit, N. E., R. H. Froend, and P. M. Davies. 2001. Identifiying the natural flow regime and the relationship with riparian vegetation for two contrasting western Australian rivers. Regulated Rivers: Research and Management 17: 201-215.	relationships found on rivers with highly predictable and strongly seasonal flow regime with low variability in monthly flows; 80% of mean discharge occurs in late winter/early spring; summer/autumn flows were less than 3% and CV of flows was high in summer; seasonality was highly predictable between years
Biological - Population/Community - Plants	% cover of annual herbs positively correlated with duration of riparian zone inundation	as # days/year riparian zone is inundated increases, % cover of shrubs decreases (can't tolerate disturbance)	Pettit, N. E., R. H. Froend, and P. M. Davies. 2001. Identifiying the natural flow regime and the relationship with riparian vegetation for two contrasting western Australian rivers. Regulated Rivers: Research and Management 17: 201-215.	relationships found on rivers with highly predictable and strongly seasonal flow regime with low variability in monthly flows; 80% of mean discharge occurs in late winter/early spring; summer/autumn flows were less than 3% and CV of flows was high in summer; seasonality was highly predictable between years
Biological - Population/Community - Plants	reduced growth rates and reduced plant recruitment in riparian plants	change in timing of high flows; loss of seasonal flow peaks	Reily, P. W., and P. W. Johnson. 1982. The effects of altered hydrologic regime on tree growth along the Missouri River in North Dakota. Canadian Journal of Botany 60: 2410-2423.; Fenner, P., W. W. Brady, and D. R. Patten. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. Journal of Range Management 38: 135-138.; Rood, S., and J. Mahoney. 1990. Collapse of Riparian Poplar Forests Downstream from Dams in Western Prairies: Probable causes and prospects for mitigation. Environmental Management 14: 451-464.	seasonal flow peaks (flood flows and dry season base flows) are lost or timing of flow peaks changes, resulting in reduced water availability to riparian plants during growing season (reduced growth rates) and/or loss of disturbance and establishment of suitable safe sites for seed germination at the appropriate time of year (i.e., when seeds are available from dispersal)
Biological - Population/Community - Plants	reduced species richness of aquatic macrophytes	change in timing of annual peak flows; spring flooding (natural flow regime) was positively related to richness; summer flooding was negatively related to richness	Robertson, A. I., P. Bacon, and G. Heagney. 2001. The responses of floodplain primary production to flood frequency and timing. Journal of Applied Ecology 38: 126-136.	Changes in the timing of the annual flood flows (spring to summer) was correlated with reductions in species richness and biomass of aquatic macrophytes.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	biomass of aquatic macrophytes; spring flooding (natural flow regime) was positively related to biomass; summer flooding was negatively related to biomass	change in timing of annual peak flows	Robertson, A. I., P. Bacon, and G. Heagney. 2001. The responses of floodplain primary production to flood frequency and timing. Journal of Applied Ecology 38: 126-136.	Changes in the timing of the annual flood flows (spring to summer) was correlated with reductions in species richness and biomass of aquatic macrophytes.
Biological - Population/Community - Plants	algal biofilm biomass (both chlorophyll a and total); spring flooding (natural flow regime) was positively related to biomass; summer flooding was negatively related to biomass	change in timing of annual peak flows	Robertson, A. I., P. Bacon, and G. Heagney. 2001. The responses of floodplain primary production to flood frequency and timing. Journal of Applied Ecology 38: 126-136.	Changes in the timing of the annual flood flows (spring to summer) was correlated with reductions in biomass of algal biofilms.
Biological - Population/Community - Plants	increased cottonwood recruitment; increased abundance of riparian cottonwoods	restoration of summer low flows and spring flood flows to mimic natural flow regime	Rood, S. B. and J. M. Mahoney. 2000. Revised instream flow regulation enables colltonwood recruitment along the St. Mary River, Alberta, Canada. Rivers 7(2): 109-125.	Dams significantly reduced summer low flows and also reduced or eliminated high spring flows - cottonwood/willow forests basically collapsed following damming. In 1991, summer low flows were tripled, in 1994 ramping flows were instituted to mimic gradual flood recession and in 1995 a 1 in 50 yr flood was allowed. Recruitment did not occur or was sparse in areas lacking mature trees and hence a seed source - so need both natural flows and seed source to establish native forests
Biological - Population/Community - Plants	change in species composition, reduced species diversity	increased variation in magnitude and frequency of flows	Rorslett, B., and S. W. Johansen. 1996. Remedial measures connected with aquatic macrophytes in Norwegian regulated rivers and reservoirs. Regulated Rivers: Research and Management 12: 509-522.	increased scouring of plants (and organic matter) occurred in riparian zone of regulated (mostly hydropower) rivers
Biological - Population/Community - Plants	increased growth/change in extent of aquatic macrophytes; expansion of macrophytes into active channel	reduction of flow variability; reduction of peak (scouring) flows; increase in stability and magnitude of baseflows	Rorslett, B., and S. W. Johansen. 1996. Remedial measures connected with aquatic macrophytes in Norwegian regulated rivers and reservoirs. Regulated Rivers: Research and Management 12: 509-522.	
Biological - Population/Community - Plants	floodplain plant community composition	frequency of floodplain inundating flows	Sparks, R. E., J. C. Nelson, and Y. Yin. 1998. Naturalization of the flood regime in regulated rivers: the case of the upper Mississippi River. BioScience 48(9):706-720.	impacts of changes in hydrologic regime on Mississippi floodplain morphology and riparian plants; anthropogenic changes in floodplain morphology also affected riparian community

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Biological - Population/Community - Plants	replacement of herbaceous/emergent vegetation with woody vegetation	reduction in frequency and duration of annual floods (frequency and duration of inundation of floodplain) leads to an invasion of formerly herbaceous communities by woody veg) - best hydrological predictors were last day of the first flood of the season and the first day of the second flood	Toner, M., and P. Keddy. 1997. River hydrology and riparian wetlands: a predictive model for ecological assembly. Ecological Applications 7:236-246.	Predicting impact of altered flooding regime on riparian vegetation; frequently predicted response is replacement of herbaceous vegetation by woody vegetation as frequency and duration of flooding decrease (i.e. peak flows reduced and minimum flows augmented). Woody vegetation has lower tolerance for inundation during growing season; seedlings of woody plants in particular are relatively intolerant of prolonged flooding, so shorter duration floods and less frequent floods allow woody plants to establish. In addition, woody vegetation may be less tolerant of drought conditions during summer low flow periods, so the combination of reduced peak flows and augmented minimum flows should favor woody over herbaceous vegetation. Structural diversity is reduced. Seven hydrologic variables, incl. several related to timing of flooding, were tested against presence/absence of woody vegetation at particular sites in Canadian rivers. (fraction of growing season during which flooding occurred; last day of first flood; length of
Biological - Population/Community - Plants	reduced plant diversity; site and landscape scales	elimination peak flows; loss of channel forming/floodplain inundating flows	Ward et al. 1999; Marston et al. 1995; Hill et al. 1998; Galat, D. L. 1998. Flooding to restore connectivity in regulated large-river wetlands. BioScience 48: 721-733.; Schiemer et al. 1998	reduced disturbance; changed disturbance regime
Biological - Population/Community - Plants	reduced plant diversity	lateral disconnection via reduced flooding, incision or levees	Ward, J. V., and J. A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research & Management 11: 105-119.	
Hydrologic Alteration	Increases in surface runoff	increases in impervious surface cover within a basin	Arnold and Gibbons 1996	10-20% increase in impervious surface cover (ISC) increases runoff twofold; 35-50% ISC increases runoff threefold; 75-100% ISC increases surface runoff more than fivefold
Hydrologic Alteration	magnitude of peak flows decreased by 40 to 50%	dams; water storage for flood control, hydrpower and irrigation	Bovee, K. D., and M. L. Scott. 2002. Implciations of flood pulse restoration for Populus regeneration on the upper Missouri River. River Research and Applications 18: 287-298.	frequency of peak flows didn't change with dams but magnitude of annual peaks did; annual peak flows reduced by 40 to 50%; reduction in peak flows affected riparian plant recruitment and possibly other floodplain dependent species
Hydrologic Alteration	33% decrease in annual flows; about 34% reduction in peak flows	water storage behind dams; blockage of river by aquatic macrophytes; water diversion for irrigation; evaporation from reservoirs	Goes, B. J. M. 2002. Effects of river regulation on aquatic macrophyte growth and floods in the Hadejia-Nguru wetlands and flow in the Yobe River, Northern Nigeria: implications for future water management. River Research and Applications 18: 81-95.	controlled and uncontrolled tributaries; controls are dam and irrigation diversion; flows decreased due to diversion of water and evaporation from reservoirs

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Hydrologic Alteration	timing of floods became less predictable	a-seasonal releases of water from storage dams	Goes, B. J. M. 2002. Effects of river regulation on aquatic macrophyte growth and floods in the Hadejia-Nguru wetlands and flow in the Yobe River, Northern Nigeria: implications for future water management. River Research and Applications 18: 81-95.	timing of floods before reglation occurred in late July/August; following regulation and increased dry season flows, floods occur much less predictably; flood timing no longer corresponds with timing of traditional rice flood-recessional farming
Hydrologic Alteration	river flows changed from ephemeral to perennial due to increased dry season flows	increased dry season flows for irrigation	Goes, B. J. M. 2002. Effects of river regulation on aquatic macrophyte growth and floods in the Hadejia-Nguru wetlands and flow in the Yobe River, Northern Nigeria: implications for future water management. River Research and Applications 18: 81-95.	dry season flows increased to provide water for flood irrigation,dry season flows were 4% of annual flows in unregulated tributary and 16% of annual flows in regulated tributary
Hydrologic Alteration			Olden, J. D., and N. L. Poff. 2003. Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. River Research and Applications	For snow and rain climatic regimes, the indices with the largest loading for the statistically significant principal components were: magnitude of average flows (MA3, MA44); magnitude of low flows (ML13, ML14); magnitude of high flows (MH17, MH20); frequency of low flows (FL3, FL2), frequency of high flows (FH3, FH5); duration of low flows (DL6, DL13), frequency of high flows (DH12, DH24), timing of flow events (TA1, TL1), rate of change of flow events (RA9, RA8). MA3 - CV of daily flows; MA44 - variability in annual flows (90th - 10th percentile) divided by median annual flows; ML13 - CV of minimum monthly flows, ML14 - mean of lowest annual daily flow divided by teh median annual daily low flow averaged across all years; MH17 - 7-day minimum flow divided by mean annual daily flows averaged across all years; MH20 - ratio of baseflow volume to total flow volume; FL3 - total number of low flow spells (<5% of mean daily flow) divided by record length in years; FL2 - CV in low flood pulse count (i.e., times in a year that flow drops below the 25th percentile
Hydrologic Alteration	lag time is shortened in urban catchments (time difference between center of precipitation volume and center of runoff volume); floods peak more rapidly	increase in impervious surface cover	Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32: 333-365.	
Hydrologic Alteration	shorter duration flood peaks in urban catchments	increase in impervious surface cover and decrease in lag time	Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32: 333-365.	

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Hydrologic Alteration	peak discharges higher in urban catchments; peak discharges increase with increasing ISC	increase in impervious surface cover	Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32: 333-365.	peak discharges were at least 250% higher in urban catchments than in forested catchments after similar sized storms
Hydrologic Alteration	magnitude of peak flows; threshold flows required to maintain riparian regeneration	flows above …..	Richter, B. D., and H. E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meadering rivers. Conservation Biology 14: 1467-1478.	
Physial - Geomorphic: Estuary	an increase in stratification and reduced mixing of surface waters with nutrient rich deeper waters occurred in estuary following years of high flows	anomalously high annual discharges (defined as >20% increase compared to previous 3 year average)	Beamish, R. J., C. M. Neville, and B. L. Thomson. 1994. A relationship between Fraser River discharge and interannual production of Pacific salmon (Onchorhynchus spp.) and Pacific herring (Clupea pallasi) in the Strait of Georgia. Can L. Fish. Aquat. Sci. 51: 2843-2855.	Very high discharges and greater volumes of freshwater entering estuary increases stratification and reduces mixing between nutrient poor surface layers and nutrient rich deeper layers; surface waters support less phyto and zooplankton and therefore productivity is lower and hypothesis is that this results in the lower numbers of salmon associated with brood years during high discharges; authors documented that during periods of weak stratification, there is a significant increase in productivity following major wind events and greater mixing; mixed layer is deeper under conditions of high freshwater discharge.
Physical - Geomorphic: Channel Form and Floodplain	meandering channel became braided (via several stages of change in channel form and vegetation) following damming; variable response of channels to decreased peak flows and decreased sediment supply downstream of dams	decreased annual peak flows; decreased frequency of peak flow events; increased mean annual flows	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 and Management 16: 543-564.	Green River, CO - changes were initial channel narrowing and decreased sediment deposition on point bars, vegetation invaded active channel, followed by channel widening, downstream acretion of channel islands and establishment of marsh vegetation on channel islands; channel has changed from meandering to braided channel; cottonwood forests have been converted to more xeric vegetation and in-channel islands support emergent marsh vegetation; reference reach (Yampa River) had vegetation communities along continuum from emergent (OBL) to early successional (willow/Populus) to Populus forest to xeric upland; Green River now just has the very wet and dry ends of spectrum

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Physical - Geomorphic: Channel Migration Zone and Floodplain	habitat diversity (number of habitats/surfaces of different ages) decreased following dam construction	elimination of floods above 2500 m3 sec-1;reduction in mean daily flows (by 80%)	Johnson, W. C. 1992. Dams and riparian forests: case study from the upper Missouri River. Rivers 3: 229-242.	Missouri River below Garrison Dam. Prior to damming 2/3 of peak flows were above 2500 m3 sec-1; after damming no flows were above this. Prior to damming, floodplain habitats were disturbed by high flows and vegetation reflected age of surfaces - young pioneer to mature vegetation - 4-5 habitat mosaic types by stage of vegetation. Following damming only the mature vegetation stage was represented. Patch diversity reduced and patch turnover basically eliminated in the absence of disturbance from the river.
Physical - Geomorphic: Channel Migration Zone and Floodplain	patch turnover rates on floodplain decreased following dam construction (turnover rates as measured by age of vegetation)	elimination of floods above 2500 m3 sec-1;reduction in mean daily flows (by 80%)	Johnson, W. C. 1992. Dams and riparian forests: case study from the upper Missouri River. Rivers 3: 229-242.	Missouri River below Garrison Dam. Prior to damming 2/3 of peak flows were above 2500 m3 sec-1; after damming no flows were above this. Prior to damming, floodplain habitats were disturbed by high flows and vegetation reflected age of surfaces - young pioneer to mature vegetation - 4-5 habitat mosaic types by stage of vegetation. Following damming only the mature vegetation stage was represented. Patch diversity reduced and patch turnover basically eliminated in the absence of disturbance from the river.
Physical - Geomorphic: Channel Migration Zone and Floodplain	Reduced physical habitat complexity on floodplain (number of different patch types; number of barren vs. vegetated sand bars)	reduction in flows to below the previous 1 in 2 yr peak discharge; stabilization of flows	Polzin, M. L., and S. B. Rood. 2000. Effects of damming and flow stabilization on riparian processes and black cottonwoods a long the Kootenay River. Rivers 7: 221-232.	Comparison of pre- and post-dam conditions using aerial photographs and vegetation ages. Prior to damming, channel migrated frequently across floodplain and floodplain contained more habitat patches, many barren sand bars and areas of new sediment deposition following floods. Following damming, channel migration has been greatly reduced and barren sand bars are absent; extent of cottonwood/willow forests has been reduced compared to pre-dam conditions.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Physical - Geomorphic: Channel Migration Zone and Floodplain	channel migration rates correlated with duration of floods above 209 m3/s (125% bankfull)	duration of flooding above certain threshold (125% bankfull)	Richter, B. D., and H. E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meadering rivers. Conservation Biology 14: 1467-1478.	Research on channel migration rates on Yampa River, CO, showed that duration of flooding above 125% bankfull was hydrologic variable most highly correlated with channel migration rates. Developed computer model based on this to simulate flood-driven changes in riparian patch types - which are tied to riparian forest succession and maintenance of native riparian forests. Tentatively set management threshold of 125% bankfull (above 209 m3/s) as target for maintaining channel migration and riparian forest succession.
Physical - Geomorphic: Channel Migration Zone and Floodplain	channel migration rate reduced; reduced habitat complexity on floodplain	reduction in annual peak flows	Rood, S. B., K. Taboulchanas, C. E. Bradley, and A. R. Kalischuk. 1999. Influence of flow regulation on channel dynamics and riparian cottonwoods along the Bow River, Alberta. Rivers 7:33-48.	Comparison of aerial photographs of floodplain pre- and post-dam to estimate rates of channel migration and habitat complexity. Effects of dams were partially mitigated where tributaries entered river and established more natural flow and sediment regime. Effects of reduced annual peak flows and sediment reudction depended on distance downstream from dam and number of tributaries and sediment sources downstream of dam.
Physical - Geomorphic: Estuary	steepening of the delta surface occurred following reductions in annual flows and increased sediment inputs	reduction in flow - diversion of 40% of annual average runoff from basin	Jay, D. A., and C. A. Simenstad. 1996. Downstream Effects of Water Withdrawal in a Small, High-Gradient Basin: Erosion and Deposition on the Skokomish River Delta. Estuaries 19: 501-517.	Steepening of delta occurred due to higher rates of deposition in the inner delta and greater rates of erosion in the outer delta. Paper discusses effects of water diversion from Skokomish River on delta, estuary and Hood Canal; extensive logging has also occurred in the basin;comparison of pre-diversion (1885) with post-diversion (1972) delta bathymetry; hypothesized mechanism is a reduction in sediment transport capacity due to flow reduction combined with an increase in sediment supply due to logging.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Physical - Geomorphic: Estuary	40% loss of intertidal habitats most commonly used by juvenile fish	reduction in flow - diversion of 40% of annual average runoff from basin	Jay, D. A., and C. A. Simenstad. 1996. Downstream Effects of Water Withdrawal in a Small, High-Gradient Basin: Erosion and Deposition on the Skokomish River Delta. Estuaries 19: 501-517.	Steepening of delta resulted in a change in the extent of intertidal habitat at different depths. Paper discusses effects of water diversion from Skokomish River on delta, estuary and Hood Canal; extensive logging has also occurred in the basin;comparison of pre-diversion (1885) with post-diversion (1972) delta bathymetry; hypothesized mechanism is a reduction in sediment transport capacity due to flow reduction combined with an increase in sediment supply due to logging.
Physical - Geomorphic: Estuary	18% loss of intertidal habitats at elevations most commonly colonized by eelgrass (Zostera marina)	reduction in flow - diversion of 40% of annual average runoff from basin	Jay, D. A., and C. A. Simenstad. 1996. Downstream Effects of Water Withdrawal in a Small, High-Gradient Basin: Erosion and Deposition on the Skokomish River Delta. Estuaries 19: 501-517.	Steepening of delta resulted in a change in the extent of intertidal habitat at different depths. Paper discusses effects of water diversion from Skokomish River on delta, estuary and Hood Canal; extensive logging has also occurred in the basin;comparison of pre-diversion (1885) with post-diversion (1972) delta bathymetry; hypothesized mechanism is a reduction in sediment transport capacity due to flow reduction combined with an increase in sediment supply due to logging.
Physical - Geomorphic: Estuary	reduction in the size of mesohaline mixing zone	reduction in flow - diversion of 40% of annual average runoff from basin	Jay, D. A., and C. A. Simenstad. 1996. Downstream Effects of Water Withdrawal in a Small, High-Gradient Basin: Erosion and Deposition on the Skokomish River Delta. Estuaries 19: 501-517.	Changes in estuarine topography and reductions in amount of freshwater entering estuary resulted in change in extent of mixing zone and salinities in estuary.
Physical - Geomorphic: Groundwater, Hyporheic Zone	increase in ground water depths on floodplain; a decline of about 1m in spring;a decline of about 2m in fall	annual peak flows eliminated; reduction in flood frequency	Prax, A. 1991. The hydrophysical properties of the soil and changes in them. Pages 145-168 in M. Penka, M. Vyskot, E. Klimo, and F. Vasicek, ed. Floodplain Forest Ecosystem. II. After Water Management Measures. Elsevier, Amsterdam.	River Dyje,evaluated flood management effects on alluvial ground water depths; hyporheic zone effects not evaluated, but significant declines in alluvial groundwater tables related to reduced flooding may also reduce extent of hyporheic zone.
Physical - Geomorphic: Channel	incision	peak discharge; duration peak flows; increased frequency of peak flows	Booth, D. B. 1990. Stream channel incision following drainage basin urbanization. Water Resources Bulletin 26: 407-417.	Documents changes in hydrology related to increasing urbanization that result in changes in channel cross-sectional area, basal shear stress, and stream power. Comparison of rural and urbanized basins in PNW, and PA; increased urbanization and impervious surfaces resulted in increased peak flows and channel widening and/or incision. Large impervious surfaces had largest effects on channel widening. No information on biological effects of channel widening.

King County

Type of Response	Effect of Flow	Flow Variable	Citation	Notes
Physical - Geomorphic: Channel	Channel widening	peak discharge; duration peak flows; increased frequency of peak flows	Booth, D. B. 1990. Stream channel incision following drainage basin urbanization. Water Resources Bulletin 26: 407-417.	Documents changes in hydrology related to increasing urbanization that result in changes in channel cross-sectional area, basal shear stress, and stream power. Comparison of rural and urbanized basins in PNW, and PA; increased urbanization and impervious surfaces resulted in increased peak flows and channel widening and/or incision. Large impervious surfaces had largest effects on channel widening. No information on biological effects of channel widening.
Physical - Geomorphic: Channel	reduced number of islands; conversion of mobile bars to stabilized vegetated islands	reduced frequency/mag of floodplain inundating flows; reduced median annual discharge	Ligon, F. K., W. E. Dietrich, and W. J. Trush. 1995. Downstream ecological effects of dams, a geomorphic perspective. BioScience 45: 183-192.	channel and floodplain changes associated with dams; also includes channel incision due to reduced sediment supply
Physical - Geomorphic: Channel	increased depth of bed scour	increased flood frequency; increased mag of peak flows	Montgomery, D. R., J. M. Buffington, N. P. Peterson, D. Sheutt-Hames, and T. P. Quinn. 1996. Streambed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival. Can. J. Fish. Aquat. Sci. 53: 1061-1070.; Montgomery, D. R., E. M. Beamer, G. R. Pess, and T. P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Can. J. Fish. Aquat. Sci. 56: 377-387.; Moscrip, A. L., and D. R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Puget Lowland streams. J. of the American Water Resources Association 33: 1289-1297.	Urbanization; increased frequency of peak flow events; increased mag of peak flows increased stream bed scour to below egg burial depths for fall spawning salmonids
Physical - Geomorphic: Channel	median width urban channels 26% greater	increase (131%) in median bankful discharge per drainage basin area in urban channels	Pizzuto, J. E., W.C. Hession, M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania.Geology 28(1): 79-82.	gravel bed rivers compared in urban and rural catchments; gravel bed rivers
Physical - Geomorphic: Channel	median sinuosity 8% lower in urban channels	increase (131%) in median bankful discharge per drainage basin area in urban channels	Pizzuto, J. E., W.C. Hession, M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania.Geology 28(1): 79-82.	gravel bed rivers compared in urban and rural catchments; gravel bed rivers
Physical - Geomorphic: Channel	pools 31% shallower in urban channels	increase (131%) in median bankful discharge per drainage basin area in urban channels	Pizzuto, J. E., W.C. Hession, M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania.Geology 28(1): 79-82.	gravel bed rivers compared in urban and rural catchments; gravel bed rivers
Physical - Geomorphic: Channel	composite Manning's n (median grain diameter, pool depth & sinuosity) 10% lower in urban streams	increase (131%) in median bankful discharge per drainage basin area in urban channels	Pizzuto, J. E., W.C. Hession, M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania.Geology 28(1): 79-82.	gravel bed rivers compared in urban and rural catchments; gravel bed rivers
Physical - Geomorphic: Channel	change in grain size distribution - removal of 2-64 mm size range from urban channels	increase (131%) in median bankful discharge per drainage basin area in urban channels	Pizzuto, J. E., W.C. Hession, M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania.Geology 28(1): 79-82.	gravel bed rivers compared in urban and rural catchments; gravel bed rivers

King County				
Type of Response	**Effect of Flow**	**Flow Variable**	**Citation**	**Notes**
Physical - Geomorphic: Channel	change in cross sectional area	increase (131%) in median bankful discharge per drainage basin area in urban channels	Pizzuto, J. E., W.C. Hession, M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania.Geology 28(1): 79-82.	gravel bed rivers compared in urban and rural catchments; gravel bed rivers
Physical - Geomorphic: Channel	increased channel width	increase (131%) in median bankful discharge per drainage basin area in urban channels	Pizzuto, J. E., W.C. Hession, M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania.Geology 28(1): 79-82.	gravel bed rivers compared in urban and rural catchments; gravel bed rivers