Environmental Flows and Adaptive Management
Physical Diversity
- hydrology
- hydraulics
- substrate
- geometry
  - temporal & spatial

Biological Diversity
- biological characteristics
- connectivity (x, y, z)
  - temporal & spatial

Channel + Floodplain → Habitat → River health
Flow (magnitude, duration, timing) and sediment (concentration, grain size) create & maintain habitat & connectivity

need to quantify relations between
flow & sediment (drivers) and habitat, connectivity & biota (response)

threshold (e.g., initiate sediment motion)
or
response curve (e.g., fish biomass vs extent & duration of floodplain inundation)
Three case studies from regulated rivers in the western United States

Hog Park Creek, Wyoming: methods used to quantify changes in physical driver variables associated with a dam

North Fork Poudre River, Colorado: methods used to quantify thresholds & response curves of physical & biotic response variables

Colorado River in Grand Canyon, Arizona: testing hypotheses of interactions among driver & response variables by observing river response to altered dam operations
Hog Park Creek, Wyoming

64 km² drainage area
subalpine meadow; sinuous, cobble-bedded, pool-riffle channel
summer snowmelt peak flow
upstream dam built during 1960s & enlarged during 1980s
corncern about enhanced bank erosion

(Gilliam 2011)
Hog Park Creek, Wyoming
Data sources for 4 study reaches

- annual resurveys of 48 cross sections & 90 bank erosion pins over 5 years
- streambed particle size distributions
- discharge from pressure transducers at two sites
- 6 sets of aerial photos from 1937-2001
- daily discharge data from dam since 1970

Analyses conducted

- Indicator of Hydrologic Alteration software used to assess changes in ecologically-based hydrologic parameters
- NCED Stream Restoration Toolbox Planform Statistics used to assess changes in meander migration rate, channel complexity and channel width between successive aerial photographs
- WinXSPro used to assess volume of channel-boundary erosion between successive cross sectional surveys (Hardy et al. 2005)
- BSTEM model used to assess effects of altered flow regime on bank erosion
Results indicate changes in flow variability in annual hydrograph reduced: peak flows ↓, low flows ↑ ratio of maximum to minimum flow decreased by > 80% low flows increased ~ 300% annual discharge nearly doubled by flow augmentation peak flow shifted to bimodal distribution rate of drop in falling limb of peak flow increased significantly

changes in channel form decreased lateral migration distance loss of complexity in form – decreased variability in width & depth, loss of beaver ponds, side channels & gravel bars increase in channel width

increased bank erosion abrupt drops in flow stage create saturated, laterally unsupported banks that fail via mass wasting
North Fork Poudre River, Colorado

900 km² drainage area
bedrock canyon; boulder-bedded, pool-riffle channel
summer snowmelt peak flow
upstream dam built 1910
concern about loss of bed mobility,
pool infilling,
lack of riparian vegetation recruitment,
drying of floodplain

(Rathburn et al. 2009)
Several studies indicate

- Reduced base flow & extreme peak flows
- Reduced sand & gravel transport – changes in periphyton, aquatic insects, & predators (fish, birds)
- Clogging of spawning gravels
- Aging & senescence of riparian forest
- Encroachment on xeric plants on floodplain
Recommendations for flow thresholds to
mobilize interstitial sediment
mobilize majority of bed material
erode stream banks
inundate overbank areas

- Interstitial fines flushed
  - Grain size distribution
  - Channel geometry
  - Entrainment equation

- Majority of bed material mobilized
  - Grain size distribution
  - Channel geometry
  - Entrainment equation

- Overbank flow occurs
  - Valley geometry
  - Channel geometry
  - Hydraulic model

- Lateral channel mobility
  - Channel geometry
  - Bank characteristics (incl. vegetation)
  - Bank erosion model

Threshold discharge
Colorado River in the Grand Canyon of Arizona

300,930 km² drainage area, > 400 km river length
bedrock canyon; boulder-bedded, rapids & pools with sand bars & backwaters
summer snowmelt peak flow
upstream dam built 1963
concern about reduced sediment yield, loss of flood peaks, rapidly fluctuating base flow (hydropower), changes in water quality, loss of sand bars, endangered fish species

(Gloss et al. 2005, Wohl et al. 2008)
Primary effects of upstream dam

decreased flood peaks
increased diurnal changes in low flows
decreased temperature & turbidity of water released from base of dam
reduced sediment yield from upstream
blocked fish passage

Secondary effects

progressive loss of sand bar & backwater habitats
reductions in number & ranges of native endemic fish species
gradual erosion of terraces (archeology, habitat, recreational use)
alteration of major rapids
Figure 9. Sequence of events established in the autumn sediment input scenario in an environmental assessment by U.S. Department of the Interior (2002) related to fine-sediment inputs and retention to trigger a 2-d, 42,000–45,000-cfs experimental high flow in January. If fine-sediment inputs do not reach specified levels, then modified low fluctuating flow (MLFF) operations, as specified in the Record of Decision (ROD) (U.S. Department of the Interior, 1996), are continued.
Changes in instantaneous discharge range downstream from Glen Canyon Dam between 1921 and 2004 (after Wright et al., 2005, Figure 1).

Water discharge from Glen Canyon Dam (power generation) and Sediment discharge from tributaries downstream from dam (coarse & fine sediment).

Geometry & stability of riverine corridor:
- constrictions at rapids
- sand bars
- habitat for riparian vegetation & terrestrial animals
- instream habitat for fish & other organisms
- recreational sites
- archeological sites

Alterations in water & sediment discharge lead to:
- increased constrictions
- loss of sand bars: loss of habitat, recreational sites, & archeological sites
- loss of channel-margin complexity & aquatic habitat
- competitive advantage for nonnative species (e.g. fish, riparian plants)

Management responses include:
- removal of nonnative species
- structural stabilization of eroding archeological sites
- indirect manipulation of geometry & stability of riverine corridor via altered flow releases from dam (limit daily flow fluctuations & allow experimental releases when sufficient sediment is input by Paria River)

Schematic diagram of sand bars associated with a tributary junction and debris fan (after Webb et al., 2005, Figure 1).

Habitat zones according to inundation frequency & flow magnitude (cfs; cubic feet per second). Flow regulation has reduced flood magnitude & frequency, and the area below the 50,000 cfs water level is now the active riparian zone (after Ralston, 2005, Figure 2).

Repeat photographs of the junction of Tapeats Creek with the Colorado River in Grand Canyon in July 1952 (left) and March 2003 (right), showing loss of beach sand (after Wright et al., 2005, Figure 3).

Wohl et al., 2008
Adaptive Management

High flow experimental releases (> peak capacity of hydropower plant, 940 m³/s)

1) March-April 1996, Q ~ 1,270 m³/s for 7 days
   increased area of backwater habitat, but changes did not persist > 1 year
   net erosion of sand from lower elevation sites

2) November 2004, Q ~ 1,200 m³/s for 2.5 days (60 hours)
   occurred in response to sand inputs from tributary Paria River
   resulted in net deposition in upstream portions of river, but net erosion
   in downstream portions of river
   continuing sediment inputs to main stem via tributary floods, 2006-2007

3) March 2008, Q ~ 1,200 m³/s for 2.5 days
   increased area & volume of backwater habitat
   widespread deposition at higher elevations along main stem
   continually evolving models of sediment budget

Organization: GCMRC, 3 programs, AMWG, TWG, PEP panels, SAB
Five stage process for implementing environmental flows & adaptive management

• identifying interactions among physical driver & physical & biotic response variables
• quantifying changes in driver & response variables associated with human-induced alterations of rivers
• identifying thresholds necessary to restore & maintain desired physical & biotic process and form
• modifying human alterations (e.g., changing dam operations) to the river in order to exceed those thresholds
• evaluate river response & adjust operating procedures as needed – adaptive management
Quantifying management implications
(Shafroth et al., 2010)

Conceptual models
basic relations between flows & geomorphic/biotic responses

Physical & biotic models
surface water
ground water
sediment
individuals, populations, communities

Flow experiments & empirical models
field monitoring
hypothesis testing
development of response curves
Bibliography

Shafroth et al. 2010