Appendix 1. Table of flow-related factors, predictor variables, and response variables used in flow-ecology studies.

Statistics	Ecological Response	Source
Magnitude (n=99), duration (25), timing (16), frequency (16), and rate of change (5)	Fish, macroinvertebrates, riparian, birds & amphibians	Poff & Zimmerman 2010 (Global review)
Frequency, duration, and magnitude of mean April flow, duration of high flows, seasonal predictability of low flow and other measures	Relative abundance of macroinvertebrate taxa assemblage	Kennen et al. 2010 (Northeast U.S.)
% alteration of annual flow, % alteration of August median flow, water-use intensity (WUI) indicator, return-flow fraction, withdrawal fraction, mean annual flow, and August median flow	Fluvial fish species richness	Weiskel et al. 2010 (Massachusetts)
Alteration: streamflow alteration class (ratio of observed magnitudes: expected), diminished maximum flow, diminished min flow (7 day moving average), Inf. minimum, Inf. maximum, and mean annual maximum (daily average)	Fish & macroinvertebrates expected:observed	Carlisle et al. 2010 (U.S. nationwide)
83 HCMs: high-flow event frequency, average flow magnitude, high-flow magnitude, high-flow duration & rate of change	Algae, invertebrates, and fish	Steuer et al. 2010 (5 U.S. metropolitan areas)
Average flow magnitude, high-flow magnitude, high-flow event frequency, high-flow duration and rate of change (from the HCM)	Changes in aquatic communities	Steuer et al. 2010 (5 U.S. metropolitan areas)
% change in peak flow; minimum flows (baseflow and late summer low flows), ratio of Q75:Q25; CV of daily flows	Warm and coldwater fish, riparian vegetation, invertebrates, recreation (rafting, canoeing, kayaking)	Wilding & Poff (2008) , Others
13 metrics: Baseflow recession, daily variation and monthly variation, in stream flow maximum , & annual daily streamflow	14 invertebrate metrics	Konrad et al (2008)
Watershed characteristics affecting mean flow, sediment, pattern/storage, connectivity, and thermal regime	Fish spp presence/absence	McKenna (GL GAP)

Withdrawal fraction (% of mean and low flow)	Fish spp presence/absence	Kanno and Vokoun 2010
Withdrawal fraction (% of mean and low flow)	Fluvial specialist richness, dominance by habitat generalist species, IBI	Freeman and Marcinek 2006
mean # of annual storms producing runoff; Q25:Q75(flashiness); diversity of natural stream substrate; % forested land near the stream channel (forest buffer).	increased dominance of tolerant aquatic invertebrates	Kennen et al. 2007
Withdrawal fraction (% of mean and low flow)	fluvial dependence, guilds, habitat generalists fish and invert assemblage structure & function	Kennen and Riskin 2010
Constancy (flow stability or temporal invariance), frequency of moderate flooding (frequency of habitat disturbance), and rate of streamflow recession	insectivorous fish communities site scores	Knight et al. 2008
Increased duration of low flows associated with imperviousness during the autumn low-flow period.	increased richness of lentic tolerant species	Roy et al. 2005
Altered storm flows in summer and autumn	richness of endemic, cosmopolitan, and sensitive fish species and decreased abundance of lentic tolerant species	Roy et al. 2005
stormflow variables and % fine bed sediment in riffles	Species predicted to be sensitive to urbanization, based on specific life-history or habitat requirements	Roy et al. 2005

Appendix 2: Meeting Agendas

Workshop 1. Developing Biological and Ecological Criteria to Protect Environmental Flows within Minnesota's Great Lakes Basin

Orientation Meeting
November 1-2, 2010, EPA Mid-continent Ecology Lab, Duluth, MN
9:30 am – 4:30 pm (Day 1) and 8:30 – 3:30 pm (Day 2)

PDF versions of Powerpoint presentations online at
http://conserveonline.org/workspaces/mn-eloha-workshop1/documents/all.html

Meeting Objectives. The goal of the meeting will be to (a) explore regional-scale approaches to protecting environmental flows and establishing biological criteria to support those approaches, (b) identify resources –both expert knowledge and existing data and tools – that can support the process in MN, and (c) agree on follow-up items to pursue in developing literature/method review, recommendations, and work plan/proposals.

DAY 1. OVERVIEW & ORIENTATION

Objective: Introduce regional ecological flows framework and process; illustrate components of water management/regulatory program(s) based upon the principles of ecological response to flow alteration using case studies

9:30 am	Introduction & Overview	K. Blann
9:45 – 10:30 am	Context: Current Minnesota Water Management Setting, Challenges & Opportunities How are flows currently managed in Minnesota, and what are the future implications of and opportunities to manage for the impacts of water withdrawals, climate change, and land use change on ecological health of aquatic systems?	D. Leuthe
10:30 – 10:45 am	The Great Lakes Compact and MN's Water Sustainability Framework: Requirements & Recommendations	R. Bowman/Blann
10:45 – 11:30 am	Introduction to Principles of ELOHA (= Ecological Limits of Hydrologic Alteration): A Robust Framework for Managing Environmental Flows	E. Kendy
11:30 – 12 noon	Case Study: Developing Ecosystem Flow Recommendations for Pennsylvania Using Expert Panels and Limited Data	E. Kendy
12:00 to 12:30 pm	LUNCH (catered on-site)	
12:30 to 1:00 pm	Case Study: Developing Ecological Flow Response Curves for Michigan Using Extensive Fish Data	T. Zorn
1:00 – 1:30 pm	Case Study: Integrating Ecosystem Flow Recommendations into Michigan's Water Withdrawal Permitting Program	R. Bowman

Tools, Resources, and Other Complimentary Efforts to Support the Understanding of Flow Ecology Relationships in Minnesota

1:30 – 2:00 pm	USGS Great Lakes Restoration Initiative Ecoflows and Great Lakes Aquatic GAP Projects	J. Stewart
2:00	USGS National Water Census [brief summary]	
	BREAK	
2:15 – 2:45 pm	Assessment of MN's Great Lakes Basin Aquatic Ecosystems: Approaches & Tools	L. Johnson
2:45 – 3:15 pm	Biological and Ecological Datasets: Development of Criteria for Bioassessment of Riverine Communities in MN	S. Niemela
3:15 – 3:30 pm	Streamflow changes in Minnesota watersheds: Observations and ecological implications	C. Lenhart
3:30 - 3:45 pm	Data & modeling tools in Minnesota for predicting streamflow response to changes in withdrawals, climate, and land use	J. Nieber
3:45 - 4:30 pm	Ecological Criteria for Protecting Ecosystem Hydrology : Additional Considerations, Tools, Data, and Models for Moving Forward in Minnesota • 3-5 min. reflection/summary from each panelist of relevant datasets, initiatives, & projects • audience input on other relevant datasets, initiatives, & projects • Identify issues to be addressed, technical challenges, data available, concerns **Panelists:** Jim Stark / Richard Kiesling, USGS Ian Chisholm/Dave Wright, MN DNR Division of Ecological Resources Jeannette Leete, MN DNR, Division of Waters John Nieber, U of MN Water Sustainability Project Princesa van Buren, MN Environmental Quality Board	
4:30 pm	Closing Comments, Questions, Logistics	K. Blann

DAY 2. WORKING GROUP ON ECOLOGICAL FLOW RESPONSE

Objectives: Review available resources; explore options and develop agreement on approaches to the development of flow alteration-ecological response curves for Minnesota systems, focusing on Lake Superior basin streams; summarize data inventory and needs; recommend next steps and potential elements for proposal(s)

8 am	Introduction & Overview of Day 2 workshop agenda & objectives Review ELOHA framework and applicability of other states' approaches in Minnesota context, based on Day 1 • Briefly discuss/review MI Ecological Flow Response curves & Susquehanna River Basin conceptual model approach

- Discussion of useful elements & unique needs based on ecological setting and existing water management framework, issues to be addressed, technical challenges, data available, concerns, etc.

8:30 – 9:30 am	The hydrologic foundation in Minnesota: data resources, needs, gaps, issues [Introduction by E. Kendy/TNC followed by group discussion]
9:30 – 11:00	Classification of aquatic systems based on response to flow alteration [Discussion of existing classifications and supporting datasets in MN]
11:00	Assessing Ecological Needs & Response to Altered Hydrology [Introduction] • *Intro presentations by Zorn, Blann, Kendy* • Identify flow-sensitive systems, species, taxa, and communities (potential indicators) that should be considered
12 noon	LUNCH (catered)
12:30 – 2:30 pm	Assessing Ecological Needs & Response to Altered Hydrology [cont'd: group discussion] • Discuss existing sources of information to support assessment of ecological response to altered flow/hydrology, e.g. datasets & conceptual models, hybrids • Discuss statistical and methodological approaches ➢ *Presentation by Downstream Strategies* • Identify potential data gaps & methodological challenges
2:30 - 3:30 pm	Report Back recommendations & feedback (TNC ELOHA team) • Proposed next steps for Minnesota: Elements of a work plan, possible proposal(s), and ideas/recommendations for funding sources; and roles for TNC, partners, and advisors

Workshop 1 Participants

1. Jesse Anderson, Hydrologist MPCA, Duluth
2. Rich Axler, Watershed/water quality researcher, NRRI, U of M Duluth
3. Kristen Blann, Freshwater Ecologist, The Nature Conservancy
4. Richard Bowman, Director, Government Relations, The Nature Conservancy, MI
5. Val Brady, Ecologist, NRRI, Sea Grant
6. Ian Chisholm, Ecological Services, MNDNR
7. Meredith Cornett, Conservation Science Director The Nature Conservancy
8. Matt Diebel, UW - Madison Center for Limnology
9. Karen Evens, TMDL Coordinator, MPCA
10. Brian Fredrickson, Planner Principal, MPCA, Duluth
11. Phil Gerla, Hydrologist, The Nature Conservancy
12. Bradley Hansen, Bioproducts and Biosystems Engineering Department, U of MN
13. Deserae Hendrickson, Duluth Area Fisheries Supervisor, MNDNR
14. Jerry Henneck, Assistant Scientist, NRRI, U of M Duluth
15. Tom Hollenhorst, Ecologist, US EPA, Duluth
16. Elaine Ruzycki, Assistant Scientist, NRRI, U of M Duluth
17. Lucinda Johnson, Researcher, NRRI, U of M Duluth
18. Eloise Kendy, Environmental Flows Director, TNC
19. Richard L Kiesling, Water quality specialist, USGS
20. Karl Koller, Region 2 Clean Water Legacy Specialist, MN DNR
21. Greg Kruse, Hydrologist, MN DNR
22. Jeanette Leete, Hydrogeologist Supervisor, Groundwater Unit, Division of Waters, MN DNR
23. Chris Lenhart, Researcher, University of MN
24. Dave Leuthe, Regional Hydrologist, MN DNR
25. Joe Magner, adjunct faculty, U of MN
26. Roy Martin, Downstream Strategies (Midwest Fish Habitat Partnership assessment)
27. Brett Nagle, Animal Survey Specialist, MCBS, MN DNR
28. John Nieber, Professor, Bioproducts and Biosystems Engineering, University of MN
29. Scott Niemela, Biologist, MPCA
30. Julie O’Leary, Minnesota Environmental Partnership
31. Dan O'Shea, River Ecologist, MN DNR
32. John Sandberg, Biologist, MPCA
33. Paul Sandstrom, NRCS, Duluth, MN
34. Tom Schaub, Hydrologist, MPCA, Duluth
35. Don Schreiner, Lake Superior Fisheries supervisor, MNDNR
36. Jim Stark, Director, Minnesota Water Science Center, USGS
37. Jana Stewart , Great Lakes Aquatic GAP USGS
38. Shann Stringer, Aquatic Ecologist, Center for Ecological Sciences
39. Deb Taylor, US EPA, Duluth
40. Annette Trebitz, US EPA, Duluth
41. Dave Wright, MN DNR, Eco Services
42. Troy Zorn, Fisheries ecologist, Michigan DNR
43. Princesa Van Buren, Principal Planner, MN EQB

Workshop 2. Developing Biological and Ecological Criteria to Protect Environmental Flows and Water Levels in Minnesota

Flow Ecology Workshop 2
June 23-24, 2011
USGS conference room, Mounds View
9:30 am – 4 pm (Day 1) and 8:30 – 3:30 pm (Day 2)

PDF versions of Powerpoint presentations online at
http://conserveonline.org/workspaces/mn-eloha-workshop

Objectives:

(1) review relevant approaches to ecological flow criteria and flow-ecology response curves that have been developed to underlie environmental flow standards in other states, and how they have worked/served (or not worked) to move flow protection policies forward
(2) discuss which elements might be adapted to Minnesota based on our existing water management framework and acknowledged needs
(3) revise and critique preliminary, testable hypotheses about ecological responses to flow alteration

<u>DAY 1. OVERVIEW & ORIENTATION</u>

9:30 am	Overview & Introductions Goals and Review of the process	Blann
10 am – 10:30 am	Current Minnesota Water Management : Acknowledged Gaps related to Defining and Protecting Ecosystem Flows	
10:30 – 11:15 am	The Stream Habitat Program's Proposal for Water Management: a cap and protected flow Discussion	O'Shea
11:15 – 12	Development of Criteria for Bioassessment of Riverine Communities in MN and Tiered Aquatic Life Use (TALU) framework	Sandberg & Niemela
12:00 to 12:30 pm	LUNCH (catered on-site)	
12:30 -12:45	The Flow-Ecology Response: Foundation of ELOHA, analogue to TALU & review of relevant literature	Blann
12:45 – 1:30 pm	Flow Ecology Models underlying State Approaches to Protecting Flows from Withdrawals [via WebEx]: • Ohio case (John Stark, TNC) • Michigan case and response (Paul Seelbach) • Discussion	
1:30 pm	Flow Ecology underlying State Approaches to Protecting Natural Seasonal Patterns in Flow and Water Level Variability • FL: Minimum Flows & Levels and Water Reservations (Doug Shaw, new Assistant State Director of TNC for MN, ND, and SD) • Discussion	
2:00 pm	BREAK	

2:15 – 3:30 pm	Flow Ecology Models underlying State Approaches to Flow Protections: Massachusetts, Maine, Connecticut [via WebEx] Protecting Timing, Pattern, Seasonal Variability: Who does it and how? *Discussion examples: Maine, Connecticut, Florida, EU Water Directive* Discussion: Minnesota's process for determining and protecting ecosystem needs, opportunities and needs	 Hutchins & Abele
3:30 – 4:00	Synthesis and Recap: Opportunities and Challenges to Quantifying Ecological Criteria to Support Environmental Flow and Water Level Protections in MN	

DAY 2. WORKING GROUP ON ECOLOGICAL FLOW RESPONSE

8:30 am	Introduction, Recap, & Overview of Day 2 workshop agenda & objectives	
9 –9:30 am	Water Sustainability in MN / hydrologic foundation: data resources, needs, gaps, issues (mapping, monitoring, modeling plans) *DNR protected water basin elevations, lake levels and hydrology, wetland protections, proposed protective thresholds for aquifer levels, and GMAs*	J. Leete
9:30 am	Classification and Status of Aquatic systems in MN • Existing protected classes & known/potential gaps in protection	Blann/Leete
	Regional sources of hydrologic alteration Altered hydrology related to land use • Discussion	Lenhart/Nieber Joe Magner
10:30 am	BREAK	
10:45 am	<u>Straw Man Exercise Part 1:</u> Defining Ecosystem Needs for Flow & Response to Altered Hydrology in MN • Minimum flows & "Caps" (based on sustainable availability) • Pattern, timing, and natural variability <u>Straw Man Exercise Part 2</u>: Expert Hypotheses Breakout Groups: Ecological Needs & Response to Altered Hydrology [Breakout group exercises with "example" hypotheses: *Species, guilds, communities, and processes sensitive to flow alteration by Region & System Classes; hypotheses about response direction and magnitude]*	
12 noon	LUNCH	
1:00 – 2:30 pm	[cont'd] Expert Hypotheses Breakout Groups: Ecological Needs & Response to Altered Hydrology	
2:30 - 3:30 pm	Synthesis & Report Back Recommendations & Next Steps	

Workshop 2 Participants

1. Ralph Abele, EPA Region 1
2. Kristen Blann, Freshwater Ecologist, The Nature Conservancy
3. Eileen Campbell, MPCA
4. Ian Chisholm, Ecological Services, MNDNR
5. Tim Cowdery, Hydrologist, USGS
6. Meredith Cornett, Conservation Science Director, The Nature Conservancy
7. Evan Drivas, Hydrologist, Minnesota DNR
8. Don Hansen, USGS
9. Linda Hutchins, MA DNR
10. Jeanette Leete, Hydrogeologist Supervisor, Groundwater Unit, Division of Waters, MN DNR
11. Chris Lenhart, Researcher, University of MN
12. Dave Lorenz, Hydrologist, USGS
13. Joe Magner, adjunct faculty, U of MN
14. John Nieber, Professor, Bioproducts and Biosystems Engineering, University of MN
15. Scott Niemela, Biologist, MPCA
16. Dan O'Shea, River Ecologist, MN DNR
17. John Sandberg, Biologist, MPCA
18. Paul Seelbach, Michigan Water Science Center, USGS
19. Doug Shaw, Assistant State Director, TNC, MN-ND-SD
20. Jim Stark, Director, Minnesota Water Science Center, USGS
21. John Stark, Ohio TNC
22. John Wells, Principal Planner, Minnesota EQB

Additional Technical Work Group/Process Participants

1. Khalil Ahmad, MPCA
2. Stacey Archfield, MA USGS
3. Val Brady, Natural Resources Research Institute
4. Bill Cole, Antidegradation rulemaking, MPCA
5. Julie Ekman, MN DNR
6. Mindy Erickson, MN USGS
7. James Fallon, MN USGS
8. Charles (Chuck) Regan, MPCA
9. Howard Reeves, MI USGS
10. Dale Setterholm, Minnesota Geological Survey (MGS)
11. Glenn Skuta, MPCA
12. Chris Sanocki, Hydrologist, MN USGS
13. Andrew Streitz, MPCA
14. Steve Thompson, MPCA

Appendix 3: Conceptual Flow Ecology Hypotheses

Region	Taxa	Guild / habitat	Species / system	EFC / Flow alteration	Season	Working Flow Ecology hypotheses	REFERENCE
Statewide	Aquatic	fish, mussels, etc.	Habitat	200% of mean annual flow	October - September	Moderately high flows (natural, seasonal) help flush sediment, maintain channel habitats, and oxygenate habitats; plus facilitate seasonal and annual movement of fish and other aquatic organisms	Multiple; see Tennant for flow recommendation
Statewide	Aquatic	fish, mussels, etc.	Habitat	60-100% QA50	October - September	60-100% QA50 is optimum	see Tennant for flow recommendation
Statewide	Aquatic	Fish & inverts	Fluvial specialists	Increased CV of daily flows	All seasons	Increased flashiness can cause loss of fluvial specialists, increase in invasives/generalists, increase in shape factor (body shape)	Arthington et al. 2002
Statewide	Aquatic	Fish & inverts	All taxa but sensitive taxa first	↑ Peak flows, freq., timing (e.g. >Q25)	All seasons	Increased flashiness can cause rapid wetting and drying leading to loss of benthic biomass; reduced survivorship following abnormal spates	Arthington et al. 2002; Bunn and Arthington
Statewide	Aquatic	Fish & inverts	All taxa but sensitive taxa first	↑ Peak flows, freq., timing (e.g. >Q25)	All seasons	Impervious surface (with threshold effects on inverts identified at 3-5% impervious) causes degradation through combination of increased flashiness, scour, and sedimentation, and water quality impacts (turbidity, contaminants, runoff, thermal impacts)	Konrad and Booth 2005, Baker & King 2010, Richards et al, Wang et al. 2001
Statewide	Aquatic	Riparian vegetation	Riparian vegetation	Ratio of high: low flows (e.g. Q25: Q75); Seasonal Q10	All seasons	Increased stability of water levels and loss of wet-dry cycles causes reduced growth and survival of native aquatic macrophytes and increased invasions of nonnatives; conversion of lotic to lentic habitat; loss of seasonal disturbance needed to maintain native vegetation and disperse seeds; loss of wetland vegetation; channel encroachment by more upland tree and shrub species	Bunn and Arthington
Statewide	Aquatic	Wild rice	Wild rice	Changes in timing ; increase or decrease in magnitude of change	All seasons	Changes in hydrology caused by (a) landscape modifications (b) artificial lake & river level mgmt, c) impervious surface may hinder wild rice development or reduce production over multiple years; increase sedimentation.	

Region	Taxa	Guild / habitat	Species / system	EFC / Flow	Season	Working Flow Ecology hypotheses	REFERENCE
Statewide	Aquatic	Fish	Habitat	↓Q10 (10% exceedance)	All seasons	Significantly reduced magnitude, timing & frequency of flood flows causes loss of seasonal connectivity & off-channel habitats used during life history (feeding, spawning & migration)	
Statewide	Aquatic	Riffle obligates	Fish & inverts	Q90 / Q50	All seasons	Significantly reduced flow magnitudes will cause local extirpation or reduced growth	DePhilip and Moberg 2010
Statewide	Aquatic	Riffle obligates	Fish & inverts	Q90	March - July (varies by spp.)	Decreased low flows during spawning & rearing reduce recruitment (see ind. species/guild info from regional flow recs)	DePhilip and Moberg 2010
Statewide	Aquatic	fish, mussels, etc.	Fish & inverts	Q90	July - Sept	Low flows result in critical impacts on DO; may reduce high velocity habitat for swimmers/riffle-dwelling fishes and species with small home ranges/limited dispersal	MPCA
Statewide	Aquatic	Riffle obligates	Fish & inverts	Q90	July - Sept	Decreases in low flow magnitudes during the juvenile growth (July-Sept) and development period reduce recruitment, adult survival, overall population size	DePhilip and Moberg 2010
Statewide	Mussels	Mussels	Mussels	Q90	All seasons	Reduced / extreme low flows increase risk of exposure and predation of mussel beds; may reduce carrying capacity; reduce individual growth & fitness, and/or cause local extirpation	
Statewide	Mussels	Mussels	Mussels	↑Q10 (10% exceedance)	All seasons	Increased magnitude/flashiness can cause habitat instability, stranding, scour; reduced availability of host fishes during spawning	Carlisle et al. 2010
Statewide	Mussels	Mussels	Mussels	↓Q10 (10% exceedance)	All seasons	Decreased magnitude/frequency of high flows can cause habitat degradation, embeddedness, aggrading, lack of appropriate sediment	Carlisle et al. 2010
Statewide	Aquatic	Riffle obligates	Fish & inverts	Thermal habitat	All seasons	Depletion of groundwater flow through hyporheic zones causes loss of refugia for sensitive macroinvertebrates & loss of fish food	Arthington et al. 2002
All coldwater	Fish	Coldwater / headwater	Brook trout	Q90	December-March	During egg incubation, redds and riffle habitat need adequate flows to oxygenate redds, flush sediment, prevent ice-up, ice build-up and scour	Schreiner et al; Persons
All coldwater	Fish	Coldwater / headwater	Brook trout	Q_D50	Nov - May	maintaining the natural variation of flushing flows, or high flow pulses, necessary to clear gravel and maintain riffle habitat before fall spawning	DePhilip and Moberg 2010

Region	Taxa	Guild / habitat	Species / system	EFC / Flow	Season	Working Flow Ecology hypotheses	REFERENCE
All coldwater	Fish	Coldwater / headwater	Brook trout	Q10/Q25	Oct - May	During overwinter egg incubation period, redds and riffle habitat must not be excessively high so that redds are scoured and eggs are flushed	DePhilip and Moberg 2010
All coldwater	Fish	Coldwater / headwater	Brook trout	Q90	Oct - May	During overwinter egg incubation period, redds and riffle habitat must be kept sediment free with adequate flows	DePhilip and Moberg 2010
All coldwater	Fish	Coldwater / headwater	Trout	Storm event flows	July - Sept	Small, storm event flows needed to flush sediment and maintain habitat	
All coldwater	Fish	Coldwater / headwater	Brook trout	Q50 / Q90	Oct - Dec	During the spawning period flows must be high enough to maintain connectivity, allowing migration to spawning areas	
L Superior SW streams (cw)	Fish	CW/Potamo drous	Coaster brook trout	Q90	Dec - Mar	During overwinter egg incubation period, redds and riffle habitat must be kept sediment free with adequate flows to prevent ice-up, ice build-up and scour	Schreiner et al.; Persons
L Superior SW streams (cw)	Fish	CW/HW	Brook trout	seasonal		During the spawning period flows must be high enough to maintain connectivity, allowing migration to spawning areas	Schreiner et al.; Persons
L Superior SW streams	Fish	CW/Potamo drous	BKT & salmon / steelhead	winter Q90		Winter low flows must not be depleted to the point where ice out and scour …	Schreiner et al.; Persons
L Superior SW streams	Fish			median flow (Qs50), watershed storage (defined as % in lakes & wetlands)		loss of mature forest ↑ range of variation between baseflow and peak flows; depressed baseflow. Significant thresholds of change in flow metrics occurred at 50-65% mature forest and 18-26% watershed storage. Watersheds with < 50% mature forest cover had higher levels of suspended solids, turbidity, and dissolved P. Thresholds for detecting response of fish assemblages to watershed storage at 11%; NPS pollution impairment thresholds detected at 5-10% storage.	Detenbeck et al. 2004, Brazner et al. 2004, 2005
Forested ecoregions esp Lk Superior	Aquatic	Fish & inverts	Sensitive taxa	flows/ thermal regime		Loss of forest cover and/or lake/wetland storage (thresholds identified at <60-75%, < 10-20% respectively) causes degradation through increased flashiness, scour, and sedimentation, and water quality impacts (turbidity, contaminants, runoff, thermal impacts)	Multiple; see Johnston et al., Richards, Brazner et al., Lake Superior Streams

Region	Taxa	Guild / habitat	Species / system	EFC / Flow	Season	Working Flow Ecology hypotheses	REFERENCE
Miss. hw reservoirs (lakes & river chain)	Fish	Lakes & slow rivers	All fish	Lake levels	Summer	Elevated water levels in recreational and flood-control mainstem reservoirs cause increased bank erosion in managed lakes, leading to sedimentation of fish habitat.	ROPE study
Miss. hw reservoirs (lakes & river chain)	Vegetatio n	Lakes & slow rivers	Floating bog	Winter flows	Winter	Elevated winter release flows from managed reservoirs causes increased winter scour in some rivers downstream of dams, particular erosion of floating bogs (thermal impact ?)	ROPE study
	Wetland/ floodplain		Wetland/flood plain	timing & duration		Wetland / floodplain habitat?	ROPE study; Arthington et al. 2011
Miss. hw reservoirs (lakes & river chain)	Aquatic plants in lakes	Lake	Aquatic plants in lakes	Lake levels	Summer	Elevated lake levels accelerate shoreline erosion and sedimentation. Lack of periodic or seasonal low water conditions inhibits the reestablishment of emergent plant beds such as wild rice, cattail, bulrush, and arrowhead that benefit by low water, as it encourages seed germination and, therefore, the expansion of emergent plant beds.	ROPE study
Miss. hw reservoirs (lakes & river chain)	Fish	Fluvial fish		Spring high flows, Delayed timing & lower magnitude floods	Spring	Riverine fish species would be impacted by unnatural hydrologic conditions: Spring flows under existing operations occur later and at a lower magnitude than they would under natural conditions. This disrupts the timing of spawning due to the lack of a correctly timed spawn-triggering pulse, and the survival of fry by increasing the magnitude and frequency of high water after hatching. High flows during the winter months induce stress on fish that have moved into slow deep pools during the winter when cold water slows metabolisms.	ROPE study
Miss. hw reservoirs (lakes & river chain)	Fish	Fluvial fish		Winter high flows	Winter	High flows during the winter months induce stress on fish that have moved into slow deep pools during the winter when cold water slows metabolisms.	ROPE study
	Fish	Plant cover	Northern pike & other species	Indirect altered hydrology		Declining emergent plant beds reduces availability of spawning and nursery habitat for numerous species including northern pike.	ROPE study

Region	Taxa	Guild / habitat	Species / system	EFC / Flow	Season	Working Flow Ecology hypotheses	REFERENCE
Miss. hw reservoirs (lakes & river chain)	Fish	Spawning & nursery	Walleye	Artificially elevated lake levels	Spring	Sedimentation in coarse-substrate spawning habitat reduces quality and availability habitat for numerous species including walleye.	ROPE study
Miss. hw reservoirs (lakes & river chain)	Fish		Whitefish	Winter drawdown / low flows	Winter	Whitefish have been identified in the past as potentially been impacted by the late winter drawdown. Whitefish spawn in the late fall; therefore, incubation and hatching can be adversely affected by declining water levels during the winter.	ROPE study
Miss. hw reservoirs (lakes & river chain)	Mussels		Mussels	Elevated summer lake levels		Sedimentation due to elevated lake levels covers hard substrates favored by many mussel species. But, mussel diversity and density is generally low; # Ind and species would be low relative to potential impacts in other areas of the Mississippi River drainage	ROPE study
Miss. hw reservoirs (lakes & river chain)	Birds		Waterfowl	seasonal pattern to which nesting is adapted		Waterfowl nesting is currently impacted downstream of the reservoirs, especially Lake Winnibigoshish and Leech Lake. In spring, water is stored for flood damage reduction, with reduced/min releases. Results in low water levels in adjacent downstream wetlands during the time when some species of waterfowl are building nests and laying eggs close to the waterline. Under more natural hydrologic conditions, water levels in the rivers would have been higher during nest building, encouraging birds to nest higher, which would decrease chance that subsequent high water would impact nests. Under current operations, once flood season has ended, flows can be and are often greatly increased from the reservoirs late in spring, and nest flooding is often observed.	ROPE study
Coldwater deep lakes	Fish	Coldwater lake spp		Temp.	Summer	Reduced groundwater inputs to lake may increase vulnerability to thermal stress / tullibee dieoffs in marginal coldwater lakes	Jacobson

Region	Taxa	Guild / habitat	Species / system	EFC / Flow	Season	Working Flow Ecology hypotheses	REFERENCE
Southern, western, central MN (Row crop > 75% and/or tile-drained watersheds)	Aquatic	All	riparian veg; hydraulic habitat; substrate ; fish; invertebrates; etc.	Increased Qbf / increased frequency of bankfull events (1.01-year, 1.5-year, 2-year recurrence intervals)	any time	Increases in the bankfull, channel-forming discharge have resulted in channel degradation, which disconnects the channel from the active floodplain. The resultant loss of the active floodplain has destabilized riparian vegetation, habitat and the riparian corridor's ability to buffer environmental stress. Subsequent channel adjustments following incision have resulted in land loss and increased sediment loads in the unstable channels. Some of the increased sediment loads are deposited in downstream, widened reaches, but silts and clays transported further downstream as an increased suspended-sediment load.	Miller 1999; Magner et al. 2000, 2004: Field evidence of channel incision (Yellow Medicine, Chippewa, Cottonwood, Blue Earth and Rush Rivers)
Southern, western, and central MN	Aquatic	Sensitive species first	All	Reduced summer low flows	any time	Decreases in summer baseflows and low flows -- whether due to irigation, increased ET by crops, or short-circuited shallow gw recharge--lead to replacement of sensitive / intolerant species with tolerant species and habitat generalists	Streitz;
Rainy River		Deep pool	Walleye adult			Altered flow reduces habitat	O'Shea
Rainy River		Fast riffle	Log perch adult			"	O'Shea
Rainy River		Fast riffle	Yellow perch young			"	O'Shea
Rainy River		Medium pool	Walleye juvenile			"	O'Shea
Rainy River		medium pool	White sucker adult			"	O'Shea
Rainy River		Medium pool	Fluted shell mussel	Subdaily variation		Peaking causes dewatering of habitat and can cause mussel mortality	
Rainy River		Raceway	Log perch & walleye spawning	Late winter/ spring		Hydropower peaking reduces spawning numbers, prolongs spawning period, and reduces success. Magnitude and pattern of spring flood plus temperatures provide cues for spawning. Winter flow conditions can affect gonad development.	Auer (1996); Khoroshko (1972)

Region	Taxa	Guild / habitat	Species / system	EFC / Flow	Season	Working Flow Ecology hypotheses	REFERENCE
Rainy River		raceway	Lake sturgeon, spawning			Hydropower peaking reduces spawning numbers, prolongs spawning period, and reduces success. Magnitude and pattern of spring flood plus temperatures provide cues for spawning. Winter flow conditions can affect gonad development.	Auer (1996); Khoroshko (1972)
Rainy River		Raceway	Silver redhorse adult			Altered flow reduces habitat	O'Shea
Rainy River		Raceway	Fat mucket mussel			Peaking causes dewatering of habitat and can cause mussel mortality	O'Shea
Rainy River		Shallow pool	Emerald shiner adult			"	O'Shea
Rainy River		Shallow pool	Silver redhorse young			"	O'Shea
Rainy River		Slow Riffle	Log perch young			"	O'Shea
Rainy River		Slow Riffle	Common shiner, spawning			"	O'Shea
Rainy River		Slow Riffle	Spottail shiner adult				O'Shea
Rainy River		Slow Riffle	White sucker young				O'Shea
Western MN		Pool, riffle,	Representativ e species		Spring (Apr -May)	Optimum community based flow for spawning habitat is natural Q25-Q75	Harvey et al. 1997
(e.g. Red Lake R, Clearwater,		and raceway			Juvenile (May -Jun)	Optimum community based flow for rearing, growth & survival is natural Q25-Q75	Harvey et al. 1997
and Yellow Medicine Rivers)					Jul-Apr	Optimum community based flow for growth & survival remainder of the year is natural Q25-Q75	Harvey et al. 1997

Appendix 4. Technical Options for Developing Ecological Flow Criteria and Protections in Minnesota based on ELOHA framework

Task 1. Hydrologic Foundation and Water Management Decision Support System (Baseline & Current Hydrologic Conditions, Classification & Assessing Alteration)

Options are not mutually exclusive—a combination of options could be implemented as part of a comprehensive approach

	A.1. Enhanced StreamStats/ FDC Regression with Water Use Information	A.2. SWAT / HSPF	A.3. AFINCH
Estimating flows @ gaged & ungaged reaches	Building upon MN StreamStats, this approach will allow the estimation of a wide range of ecologically-relevant static regression flow statistics (low flow to high flows). FDC regression approach will develop regression equations to estimate flow exceedence stats (e.g. Q1-Q99) and will develop a daily time series at ungaged sites using a Flow Duration Curve transform approach. This Flow Duration Curve transform will require an approach to link index gages to ungaged sites.	Baseline flow conditions simulated through rainfall-runoff modeling through SWAT or HSPF.. Current flow conditions developed within the watershed model application by developing a spatial water use database that can be used to estimate current flow time series based on relatively simple equations. Use HSPF and/or SWAT for development of detailed baseline and current condition simulations. Would permit assessment of impacts of land use scenarios and more robust estimates of baseline flows.	AFINCH for estimating monthly flows and distributing estimates throughout a network
Strengths	StreamStats already under development in MN, so peak flow estimates have been derived.	SWAT models have been developed for RRB, several St. Croix & MN River watersheds, and Root River. HSPF models developed for Minnesota River basins. Models account for land use alterations as well as withdrawals and are flexible for scenarios and decision support	AFINCH completed for MN Great Lakes Basin; can account for water use and adjust equations based on gaged data
Weaknesses/Limitations	Doesn't account very well for historic legacy of land use change & surface drainage modifications; not as flexible for defining current / historic / baseline/future conditions	Non-trivial problems in parameterizing and integration of SWAT models; soils data lacking for Lake Superior basin watersheds. No rainfall-runoff models can thoroughly account for historic conditions	Daily flows are extrapolated from monthly flows; violates assumptions of regression outside of range of calibrated values; only available in the short-term for Great Lakes Basin watersheds through GLRI/GAP
Cost	$100 – 150,000/year	Depends on how many pilot watershed applications. Some models already developed	$10,000 (initially obtaining data)
Timeline	3 years	1-3 years for pilot 8-digit HUC	1 year
Potential Funding Sources	USGS and state match	MPCA, USGS, MDNR	?

Task 2. Assessing Hydrologic Alteration

	B.1. Existing flow record	B.2. SWAT/HSPF	B.3 Existing Estimates
Assessing Hydrologic Alteration	Analyze flow changes over a 20-40 year period of record, using flow gage and climate records with database of cumulative water use (ground water and surface water) for comparison at pour points. Use regional reference gages for baseline conditions.(e.g.: Carlisle et al. 2010)	Baseline and current condition hydrologic data could be established based on output from existing models developed to support TMDL assessment and planning. Relevant scenarios for current, baseline, and future conditions using expert input. Link hydrologic alteration assessment tool (IHA, HIT/HAT, or	Use DNR Watershed Assessment Tool to describe current conditions, integrating information from a surface & ground water use database to estimate impacts on. Link hydrologic alteration assessment tool (e.g. IHA, HIT/HAT) to Water Budget Application.

		newly recreated) to model output.	

Task 3. Modeling surface-groundwater interactions to account for surface and groundwater withdrawal effects on streamflows and water levels

Description	Assume instantaneous effect of groundwater use.	Cumulative water use & appropriations data spatially explicit and linked to simple regional groundwater models (?) daily flow conditions based on relatively simple assumptions (e.g. STRMDEPL for groundwater withdrawal)	Detailed studies based on hydrogeologic atlases and well log studies	Soil Water Balance model (Thornthwaite and Mather)	Gerla Method 1 or 2 (MODFLOW)
Strengths / weaknesses	Not very accurate	Simple assumptions; accurate enough for screening purposes	Long time frame for completion	Under development by MPCA with DNR & USGS	
Cost & timeline	Inexpensive and in some places adequate for screening	?	$MIllions	"	$100-150K
Potential Funding Sources	USGS and state match			"	

Task 4. Aquatic System Classifications

	B.1. Ecologically Based	B.2. Hydrologically-based (HIP)	B.3. B1 or B2 classification with addition of lentic systems	B.4. Goal Condition based on ecological potential modified by management expectation	B.5. Goal Condition based on ecological potential modified by management expectation
Classification	Classify aquatic system types using MPCA IBI classification, USGS hydrologic regions, and other hierarchical biological– physical models.	Apply USGS Hydroecological Integrity Assessment Process (HIP) to Minnesota river systems. Identifies a set of non-redundant and ecologically relevant hydrologic indices for 11 subcomponents of flow for each stream type.	Add classification of lake and wetland basins based on hydrologic residence time, importance of groundwater to budget, ecological importance of variable water level fluctuations, or other "hydrologic" components identified as ecologically relevant through expert workshops, literature, and analysis. Wetlands – "No Net Loss" and WCA Special classes: Calcareous Fens	**Protected Classes -** Classes based on variable levels of protection and baseline expectations - MN currently pursuing a Tiered Aquatic Life Use (TALU) designation similar to that of Ohio, based on ecological potential and modifications "Critical habitat" designations with higher levels of protection - Trout Streams (=coldwater) - SNAs, T&E species - Federal, state, and local land and water resource plans with which permits must be consistent - Outstanding & Exceptional resource water designations (OERW)	"natural potential" system classification modified based on variable condition goals and expectations for different baseline starting point conditions and regions of the state: e.g. higher levels of protection for higher quality occurrences, SNAs, Outstanding & Exceptional resource water designations (OERWs), designated trout, endangered species, critical or sensitive habitat (as designated in local, state, and federal resource plans), etc. DNR working on "sensitive shorelands" designation…
Strengths	Classifications already exist ; simple framework. Biological data have already been assembled through MPCA IBI and Lake Superior assessment programs.	-Hydrologically based -regional hydrologic models for synthesizing flow conditions across a region and the development of flow-ecology response relations for each stream type can be added.	Several statewide lake and wetland classifications have been developed (Schupp, DNR management , TNC, WCA classes)	Critical area maps already developed for many areas, regions, and types of systems that are priorities for protection	
Weaknesses or Limitations	Doesn't include lentic systems, regulated lakes & reservoirs	Requires additional analysis and literature review	Requires additional analysis and literature review Poor/minimal protections for temporary and ephemeral wetlands classes		
Timeline	*Coldwater IBI classification will be completed in January 2011 and available for use*	1-5 years to address data gaps	1-5 years to address data gaps	See TALU timeline	

Task 5. Linking Flow Alteration to Ecological Response to Identify Ecological Criteria and Thresholds

	A. Hypothesis development through expert consultation	B. Flow-ecology relationships based on expert consultation with existing data	C. Flow-ecology relationships based on existing data	D. Flow-ecology relationships based on new & existing data
Description	Use expert workshop series to develop conceptual models of flow-ecology relationships and a basis for hydrologic standards (*see also Appendix 3*). Existing instream flow studies, expert knowledge, and flow-ecology relationships from habitat suitability models and literature would be used to develop these conceptual flow-ecology relationships. Site based decision making and application (current model)	**Combine conceptual model approach with MN IBI data and Instream flow studies.** Use expert workshop series to develop conceptual models of flow-ecology relationships and a basis for hydrologic standards. Existing instream flow studies, expert knowledge, and flow-ecology relationships from habitat suitability models and literature would be used to develop these conceptual flow-ecology relationships. Habitat suitability method could also be used to develop adverse resource impact curves based on magnitude of departure from community-based flow (CBF) bracketed recommendations. (1) Pre-Post comparisons - for sites with adequate hydrological and biological data, test hypotheses about biological responses to hydrologic changes	**Flow-ecology relationships based on existing data:** Use existing state biological and hydrologic data to develop flow-ecology relationships for major aquatic system types across MN. Flow component statistics could be based on existing gage data and statistical models as well as on AFINCH monthly data for MN Great Lakes pilot approach (available in March). Multiple options for statistical analysis (see Poff and Zimmerman 2010 as well as attached bibliography). Could include one or more of the following: (a) calculated expected/observed metrics based on fish predictions and flow predictions from Great Lakes Aquatic GAP. Flow components based on Lorenz regional equations where actual data is lacking. (b) Statewide or regional landscape analyses - relate species, guild, and / or community metrics data to sites with varying degrees of flow alteration (e.g. Knight et al 2008 or Freeman et al, using existing data & estimates of hydrologic alteration). (c) Fish suitability curves – characteristic vs. thriving. Relate fish (or other taxa) presence data to flow statistics at sites where hydrologic data available (modeled after approach taken in Michigan Water Withdrawal Assessment Tool), supplemented by analysis of additional flow components.	**Flow-ecology relationships based on data:** Develop and implement new assessment program to document impacts of flow alteration across a gradient of river types and hydrologic alteration. This assessment approach could: (a) be statewide to complement existing biomonitoring programs or (b) focus on a particular watershed or group of similar watersheds of interest. Either effort would likely build upon A-C
Cost Ranges	Up to three workshops to bring scientists in to provide input and to summarize results in reports workshop preparation, including: compilation of existing instream flow/habitat studies, organizing and hosting workshop(s), & summarizing hypotheses and conceptual models based on input.	See previous column. Requires in-kind support from various experts within the agencies.	(a) $50K for pilot application in Great Lakes basin streams based on GL Aquatic GAP data products (b) $100-300K for statewide (or basinwide) analysis; (c) $100-150K to plot fish versus flow alteration, determine optima, create curves. Fish curves could be developed by DNR hire, university, or private consultant bid .	For: (a) initial investment required for monitoring design approach ($75-100K) and $200,000 and up per year to implement. For (b): $150,000-250,000 based on size of watershed(s) and parameters measured
Time of Development	0.5 – 1 year	1 – 2 years depending on availability of flow data	(a) Depends on completion of hydrologic foundation for Great Lakes Basin streams /statewide (b) 2-3 years with major effort and university partners	Depends on completion of hydrologic foundation
Strengths	Pooled expertise & experience. Rapid output useful to develop both initial standards and as	Instream flow criteria/habitat suitability models already developed for 10-20% of rivers in Minnesota for		

	hypotheses for quantitative analysis. Does not require completion of hydrologic baseline and current conditions statewide. Expert knowledge should inform any flow-ecology analyses and hypothesis testing. This step should be part of any approach.	a range of historical flow conditions; could be adapted to broader regions. Broader applicability, with the potential to define quantitative relationships between flow alteration and ecological conditions. Use of statewide database provides large enough sample size to provide statistical strength. Does not require biological data collection. Methods from other states / watersheds (e.g., PA, MI, GA) could be applied. Biological data have already been assembled through MPCA IBI and Lake Superior assessment programs.		
Limitations	Limited quantitative conclusions possible. Questions about repeatability, objectivity, and policy credibility. Dependent on subject experts available for participation. Requires ability to find experts that have statewide knowledge.	Comparability of biological samples due to variability in sampling procedure & community types. Confounding factors that impact biological integrity (e.g., water quality). Ensuring long-term effective database management. Relies on flow and biological sampling data collected for other purposes. Data available may not cover all environment types.		For (a): Difficult and time-consuming to coordinate and implement at a statewide basis. Could be done on a rotating basin basis to limit the logistical difficulty. Will take time to accumulate enough data to be meaningful for this type of assessment. For (b): High cost and effort to implement and may provide results limited in geographic applicability
Statewide Applicability	**Yes**	Only where IF models and hydrologic data developed & available		
Regional Applicability	**Yes**	**Yes**	**Yes**	**(a) Yes (b) Maybe**
Potential Funding Sources	EPA Healthy Watersheds, MGLP & GL FHPs	Great Lakes Protection Fund; EPA Healthy Watersheds, MGLP & GL FHPs		

Task 6: Decision Support Applications/Approaches

Decision Support Applications	Screening Application	Watershed Assessment Tool	Land Use Recharge / Discharge calculators for Integrated Land-Water Planning	Ecosystem Services models
Description	A tool analogous to the Michigan WWAT, PA WAST that users/applicants can use to determine the relative "risk" from proposed withdrawal	18 assessment metrics including a flow variability metric derived from the IHA. Could build on MA SYE	Based on SWAT or other distributed watershed model, estimate how changes in land use would affect streamflows in a manner similar to the water availability screening tool. Designed for watershed and land use planners.	Integrated Land-Water planning scenario models. See Muskegon River, MI; Willamette; USFWS INVEST; Paw Paw, etc . for examples
Timeline	2-4 years	Initial WAT to be completed 2011	3-7 years	5-20 years
Strengths/weaknesses		User interface Alpha version soon to be released		