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Stream health: incorporating the human dimension to advance stream ecology

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Abstract. A healthy stream is an ecosystem that is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations. The concept described in this paper explicitly incorporates both ecological integrity (maintaining structure and function) and human values (what society values in the ecosystem). Stream ecologists who want their research to contribute to improving conditions in flowing waters require concepts like stream health, which will stimulate research in directions that will be more effective in restoring and preserving the unique organisms and ecosystems they study. Determining what is a healthy stream requires integration of stream ecology with disciplines such as economics and political science, because a concept of stream health must take into account the human attitudes and social institutions that are a part of the stream's societal watershed. New and fruitful directions for stream research lie in developing operational measures of stream health, which include the human dimension and move beyond identifying symptoms of ecological stress, and in elucidating the ecological processes and human actions that maintain stream health.

Key words: indicators, biomonitoring, social sciences, ecosystem goods and services, ecosystem health, ecological integrity.

My objective in this essay is to develop a concept of ecosystem health that explicitly incorporates societal values and to discuss how application of this concept could advance the field of stream ecology. Stream health is not a concept that currently guides lotic research; yet answering the questions of what is a healthy stream and what are the processes that maintain health will advance the discipline, will permit more effective communication with the public that both supports and uses stream research, and will stimulate stream ecologists to link their discipline more effectively with others such as economics, sociology, and political science. It will lead to a more integrative science of stream ecology that is able to contribute to improving conditions in flowing waters.

This essay is structured around 3 questions: 1) What is a healthy stream? 2) What is the need for and the opposition to a concept of stream health? 3) How would stream ecology be different if stream health were a central concept?

What is a healthy stream?

The term "health" comes from a Germanic root meaning "whole" or "uninjured" (Oxford English Dictionary 1971). Haskell et al. (1992, p. 9) provide a working definition of ecosystem health: a healthy ecological system is sustainable; it is healthy "if it is active and maintains its organization and autonomy over time and is resilient to stress." Yet ecosystem health cannot be assessed on purely ecological grounds. Rapport (1989, p. 128) argued, "judgements on ecosystem health also involve taking into account more than strictly ecological functions (e.g., considerations of the human uses and amenities derived from the system)." Accordingly, I shall argue that a healthy stream is an ecosystem that is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations. This concept explicitly incorporates both ecological integrity (maintaining structure and function) and human values (what society values in the ecosystem).

This concept of health is different from that proposed by Karr (1995, p.101), who distinguished health from integrity: "integrity refers to the capacity to support and maintain a balanced, integrated, adaptive biologic system having the full range of elements and processes expected in the natural habitat of a region", whereas health "implies a flourishing condition". According to Karr (1995), integrity is judged with reference to sites structured by evolutionary and biogeographic forces and little human influence, whereas health refers to the desired state of a site intensely used by humans (e.g., a cultivated field) but does not apply to natural ecosystems. I accept Karr's definition of integrity and agree that ecological integrity and ecological health are not the same, but I find his concept of health too restrictive. A concept of health does not only apply to sites intensively used by humans, because that would imply that humans derive value only from ecosystems they have engineered. The ecosystems of the world represent a continuum of human influence, and to be truly useful, a concept of health should be applicable to all global ecosystems. An assessment of health requires a clear statement of what it is that society values in or from the ecosystem. Implicit in Karr's definition of health is the assumption that humans value productive ecosystems. An association of health with productivity is natural in a growth-oriented society such as ours (Rapport 1989); yet productivity is not the only ecosystem attribute valued by society. Hence the concept of health proposed here explicitly incorporates societal values which include but are not restricted to productivity.

After providing a historical perspective on the development of the concept of ecosystem health, Scrimgeour and Wicklum (1996) accept Karr's definition of health. However, they find the concept "troublesome" because decisions on the preferred state for an ecosystem are societal not scientific. Stream health is not something that can be objectively assessed solely by ecologists. I agree. Its assessment requires input from ecology and from other disciplines and perspectives to clarify societal values. Stream health is not a purely scientific concept. Therein lies its value, because the research problems where such a concept is relevant (e.g., loss of native species, altered hydrologic regime, degraded water quality) are not exclusively scientific problems.

Steedman (1994) states that he accepts Karr's definition of health, but then applies a concept of health to natural as well as human-engineered ecosystems. Steedman's use of the term health appears to be closer to what is proposed here. He recognises that societal values are inherent in any assessment of ecosystem health: "most important is the need to explicitly address public perceptions and values in the calibration of ecosystem health measures" (Steedman 1994, p. 606). Measuring ecosystem health requires "scientifically based decision rules and benchmarks set in a well-documented social and cultural context" (Steedman 1994, p. 608). An ecologist's definition of health is but one perspective. Ecologists value the products of natural evolutionary and biogeographic processes, i.e., ecological integrity (Angermeier and Karr 1994, Karr 1995). Assessing ecosystem health requires ecologists to engage the public in debate to establish what society values in the ecosystem. An increasingly interested and informed public in a democracy will not simply accept a scientist's assessment of the desired condition of an ecosystem (Steedman 1994). Ecologists have a critical role to play in this debate: educating the public about ecological integrity, proposing reasonable alternative objectives for desired ecosystem conditions, and identifying the feasibility and ecological consequences of realizing society's goals for the ecosystem.

Scholars in the field of environmental ethics distinguish the instrumental from the intrinsic value of an object (Sagoff 1992). For example, the instrumental value of biodiversity is its worth when put to human use, e.g., in prospecting for new medicines. Recognizing the intrinsic value of biodiversity is acknowledging that species have a right to exist without reference to their value to humans. Ecologists tend to value intrinsic value, but the general public probably puts more weight on instrumental value. To be useful to a policy-maker, measures of stream health need to recognise both instrumental and intrinsic values of the stream. One way to develop such measures is to specify the goods and services valued by humans and provided by streams (Table 1) and to devise measures of health that can be related to the stream's capacity to continue providing these goods and services.

Conflicts often occur between different instrumental values and also between instrumental and intrinsic values; optimizing for one value may sacrifice another. The same problem arises in ecological restoration: setting goals for restoration requires value judgements (what is desired), and segments of society differ in their values (Policansky 1993). Ecologists help identify where conflicts will arise, but solution of the problem requires societal debate and is one for the policy-maker to address. Ecologists can also provide measures of health that reflect ecosystem integrity as well as the ability of streams to

TABLE 1. Examples of goods and services valued by humans and provided in perpetuity by healthy streams.

Goods	Services
Clean water for drinking, washing, and other uses	Cleansing and detoxifying water
Adequate supply of water for irrigation and industry	Producing fish for angling
Uncontaminated foods (e.g., fish, crayfish, shellfish)	Reducing sediment inputs to coastal zone
Challenging waterways for kayaking	Providing aesthetic pleasure
Sites for swimming	Maintaining water supply
An environment for contemplation and spiritual renewal	Decomposing organic matter
Unique species to observe	Storing and regenerating essential elements

provide valued goods and services once those values have been defined.

Another attribute of a healthy stream is its ability to recover from disturbance, i.e., its resilience. Resilience has long been recognized as a component of ecosystem health (Rapport 1989, Arrow et al. 1995), yet it is so difficult to quantify that some have questioned its usefulness in assessing environmental health (e.g., Karr and Thomas 1996). Studies of resistance and resilience of the stream biota to disturbances have a strong tradition in stream ecology. Mackay (1992) reviewed many of these studies and identified behavioral and ecological traits of taxa that could be used to predict a stream's ability to recover from a disturbance. Stream ecologists have analyzed recovery of lotic ecosystems from a variety of disturbances (e.g., Yount and Niemi 1990); using rate of recovery as a measure of health has not been explored. Assessing the ability of a stream to remove a pulse of nutrients or to recover from an extreme flood or to recover from a toxic spill are potential indicators of health that can be measured either by planned experiment or by taking advantage of events that have occurred (e.g., Lamberti et al. 1991). Streams that frequently experience floods and droughts recover rapidly after disturbance, but the rate of recovery is dependent on the nature of the recolonization pool (e.g., Stanley et al. 1994). Hence using rate of recovery from disturbance as a measure of health could not be an absolute measure but would have to be expressed relative to recovery rates in nearby streams.

In the absence of broadly accepted indicators of ecosystem health, the most simplistic indicators of environmental condition have been used by those asking questions in environmental policy. For example, economists have noted that the relationship between per capita income and some measures of environmental quality has an "inverted U shape" (Arrow et al. 1995). Some interpret this to mean that at early stages of economic development, pollution is an acceptable side effect of economic growth; but as incomes rise, people develop greater concern for environmental protection; hence economic growth is good for the environment (Arrow et al. 1995). Simply using concentrations of individual pollutants as a measure of environmental condition leads to the inaccurate conclusion that improved environmental quality is a consequence of economic growth; the fallacies in this approach have been articulated (Arrow et al. 1995). Indicators of stream health must reflect the complexity of goods and services provided by streams, and not simply the concentrations of one or a suite of pollutants at a series of sites (Karr and Thomas 1996, O'Neill et al. 1996).

Most assessments of ecosystem health have been based on the definition of health as the absence of disease, which in streams means the absence of stress caused by human pollution, such as acid deposition, toxins, insecticides, sewage effluent, soil erosion, etc. (e.g., Schaeffer et al. 1988). Toxicology is the current focus in the field of ecosystem health based on the types of papers appearing in journals such as the *Journal of Aquatic Ecosystem Health*. A focus on disease has provided insight into how systems change under stress (e.g., Schindler 1987) and has resulted in indicators of health that measure loss of species, vulnerability to pests, or alteration of ecosystem processes. Early warning of stress is provided by measures of life-table parameters of sensitive, short-lived species that are poor dispersers and by measures made at locations in the food web where redundancy, immigration, or both, are low (Schindler 1990).

Using the biota as indicators of stress to the ecosystem has proven successful (e.g., Rosenberg and Resh 1993). Indices based on fish or macroinvertebrate assemblages have proven to be useful measures of stream health and are widely applied today (e.g., Karr 1993). Still lacking is a wealth of evidence linking these structural measures and the functional attributes of streams that the general public values. Wallace et al. (1996) showed the linkages between structural and functional measures of stream health in a headwater Appalachian stream, but similar analyses are needed for a wider range of stream types.

Just as good medical practice is more than curing disease, so assessing and maintaining stream health is more than detecting and reducing ecosystem stress. Current practice in medicine emphasizes preventive medicine. Physicians are beginning to focus on wellness rather than illness, on preventing disease through changes in lifestyle. Many of the most striking previous improvements in human health (largest numbers of people affected) were achieved through prevention of disease by water purification, immunization, or stopping cigarette smoking (Rapport 1989).

A focus on wellness would also be a fruitful approach when incorporating a concept of health into stream ecology. Rather than simply assessing ecosystem health, a stream ecologist could also work on ways to achieve and maintain stream health. This will require collaboration with disciplines whose focus is on humans and their institutions, because modifications in human behavior will be necessary to achieve stream health. Minns (1995) proposes a framework for using a wellness approach to ecosystem health, 4 principles of which I discuss here:

1. Management should be adaptive because uncertainty will always exist, and knowledge will always be incomplete (Minns 1995). Adaptive management consists of experiments based on current understanding of the system, designed to test that understanding, monitored for their effect, and altered as needed. Engaging ecologists in this process may require some changes in behavior: "Ecologists spend too much time trying to understand problems before they take action. They may be incapable of contributing useful solutions because they get lost in the details of natural environmental variation" (Karr 1995, p. 105).

2. A scale of reference is needed. Minns (1995) proposed recognizing some historical state and the potentially most degraded state if current trends continue. The present can then be located on that scale, and the preferred sustainable state identified. RIVPAC, a system for stream health assessment in Britain, has taken a somewhat different approach, using the least disturbed streams to establish one end of the scale of reference; the other end of the scale can be established by studying highly disturbed sites (Wright 1995). This process of establishing the scale of reference is analogous to determining optimum weight charts for humans; ideal weight has changed as more data on health effects became available and as human concepts of beauty changed. Similarly, the preferred state for a stream will change as ecological understanding of the system grows.

3. Maximum extent of allowable change should be established. What is critical may not be the actual value of an indicator of health, but the extent and direction of its change (Minns 1995).

4. Indicators of health should reflect both ecological processes and human institutions. Indicators should reflect the interdependency among ecology, social/political institutions, and economics: ecological processes set the limits for what human activities are possible; human institutions (laws, culture) are dependent upon and influence ecological processes; economic systems require human and ecological resources and also affect them (Minns 1995).

A photograph of a fishing boat stranded on the sands of the former Aral Sea is a poignant reminder that economic and social institutions affect ecological health. The societies that have showed the greatest improvement in urban environmental conditions have been those with the strongest democratic institutions (Karr and Thomas 1996). River conservation organizations recognize the critical role of social institutions. When making decisions on where to take action, the human setting is always considered. Conservation organizations consider not only if a river has ecological, social, or cultural attributes that make it worthy of conservation, but also if it is threatened by human activities, and whether a champion for the cause of conservation can be found.

Because human institutions influence ecological health, indicators of wellness need to incorporate measures of those institutions. This is not something ecologists can do alone. It is something that must be done in conjunction with colleagues in the social and economic sciences. A focus on wellness requires that stream ecologists engage these related disciplines, just as we have engaged entomologists, physiologists, hydrologists, geochemists, and geomorphologists in the past.

What is the need for and the opposition to a concept of stream health?

Despite ever-increasing numbers of aquatic ecologists and publications about stream ecology, flowing waters continue to be threatened by altered hydrologic regime, species extinction or threats of extinction, habitat degradation, and poor water quality (e.g., Benke 1990, Naiman et al. 1995). It seems unlikely that more of the same kind of stream research will reverse this trend. Stream ecologists who want their research to contribute to improving conditions in flowing waters require concepts that stimulate research in directions that will be more effective in restoring and preserving the unique organisms and ecosystems they study. Incorporating a concept of health into stream research offers one approach to meet this need.

Stream ecology will benefit from a concept of stream health for the same reason that medical science has benefited from a concept of human health. The definition of health in medical science is not precise (Rapport 1989); yet medical science has clearly prospered and progressed because the concept provides a goal that can both focus research and be understood by the public and policy-makers. Importantly, that goal is valued by the public, who are supporting and using the results of the research. It can do the same for stream ecology. Policy-makers and the public need simple, understandable concepts like health to help identify what it is about a stream that is important (Shrader-Frechette 1994). There are an infinite number of ways to describe nature, and the way chosen depends in part on the audience. The concept of stream health offers a view of nature that is useful for an audience of managers, policy-makers, and taxpayers.

Ecologists are reluctant to use value-laden concepts like health (e.g., Wicklum and Davies 1995). The term health is value-laden because a value judgement about the preferred state of the ecosystem is implicit in its assessment (Policansky 1993). Scientists are reluctant to use value-laden words like health because it is argued that science is neutral; yet the path of scientific research is greatly affected by the values held by agencies and individuals who fund research and by peers who review proposals and papers (O'Brien 1993). There are many correct descriptions of nature, and "the belief that nature is, or can be, measured and described before one decides what is important is a dangerous illusion" (Norton 1995). Ecologists make value-driven decisions when deciding what research questions to answer. If a dozen stream ecologists were each asked to design a research program on a given stream, the result would be a dozen different proposals designed to answer different questions. Some programs would investigate evolution or behavior of insects or fish; others might address questions about nutrient cycling or algal assemblages. The questions asked are a result of what a scientist thinks is important about a particular system. It begins as a subjective, value-driven process. Once the question has been asked, the objective scientific method is used to answer it; but deciding what question to ask is subjective.

Reluctance to embrace the concept of stream health is also a consequence of individual differences in approach to conceptualizing problems. Stream health is an analogy, a metaphor that provides inspiration and insight for some. Others see it as a threat, arguing that use of the metaphor leads decision-makers in the wrong direction and that a metaphor like health is not an observable property (Suter 1993). Society would benefit from ecological metaphors expressed as indices that are reported along with other indicators of well-being, such as economic indicators. Economists admit their indices are not perfect; yet release of the Index of Leading Economic Indicators affects the stock market. Release of indices of stream health could have a similar impact on policy decisions affecting water resources.

Health is a metaphor with value for structuring research questions and effectively communicating results. In an analysis of case studies of ecosystem management, Gunderson et al. (1995) identified the effective use of metaphors and symbols to communicate and to develop a set of shared values as one of the strategies common to examples of successful ecosystem management. For Chesapeake Bay, it was the metaphor of the Bay as everyone's backyard; for the Great Lakes it was the concept of ecosystem health and integrity (Gunderson et al. 1995).

The concept of health has been criticized for implying that ecosystems are organisms (e.g., Suter 1993, Wicklum and Davies 1995); yet it is not necessary to view a system as an organism to apply a concept of ecosystem health. Although economic health is frequently discussed, no one views the economy as an organism. Ecologists deal with differential exposure of different parts of a loosely linked, complex, non-homeostatic system; the system is less robustly defined than the human body, its dynamics are less tractable, and alternative states are not so easily fully characterized (Kelly and Harwell 1990). These characteristics make ecosystem health harder to determine, but do not make the concept inappropriate. The same criticisms apply to the economy, yet economic health has proven to be a useful concept.

Single indices of health can be misleading (Suter 1993). Ecosystem health has been criticized as a concept because there are no analogs for pulse or temperature (Kelly and Harwell 1990); yet no physician would use only those measures to assess health. A multiplicity of indicators of stream health is needed, just as there are a wealth of medical and economic indicators. The key is to link specific indicators with ecosystem components and processes that are valued by society. A diversity of indicators is needed to reflect the complexity of ecosystems and the wealth of goods and services they provide society.

How would stream ecology be different if stream health were a central concept?

For a concept of stream health to be of value in stream ecology, it must take into account the human attitudes and social institutions that are a part of a stream's societal watershed, by which I mean the social structures and political institutions that directly influence ecological structure and processes in the stream. Applying a concept of stream health will require interdisciplinary dialog, synthesis, and experimentation to seek novel and effective solutions to the crises faced by rivers and streams in a world transformed by human actions. If humans are the dominant species on earth, it seems logical to incorporate the human dimension in stream research by collaborating with disciplines whose object of study is humans and their institutions. Ignoring the human dimension means omitting some of the most important forces shaping stream ecosystems globally. The Challenges report recently completed by the American Society of Limnology and Oceanography concluded that limnology is poorly connected to application (Lewis 1995). This conclusion is not entirely surprising: if human society is not explicitly a part of conceptual models in the discipline, why should its research meet the needs of human society? Our society is ill equipped to deal with the freshwater crises it confronts (e.g., Postel et al. 1996), in part because aquatic science has been poorly connected to the sciences that study human institutions. The ideas and priorities embodied in the Freshwater Imperative seek to improve this condition (Naiman et al. 1995).

Among the specific actions that interested stream ecologists can take is simply to begin assembling the analog of human height/weight charts for streams, as is being done in several countries (e.g., Bunn 1995, Resh et al. 1995, Wright 1995). Identifying, understanding, and protecting regional reference systems would be a valuable scientific advance because a useful concept of stream health is regional and relativistic. This is precisely the scale that the Freshwater Imperative identified as being most relevant (Naiman et al. 1995). Angermeier and Karr (1994) consider integrity to be "the presence of all appropriate elements and occurrences of all processes at appropriate rates." Hence there is a need to compile data on regional reference systems to clarify the ranges to be expected for "appropriate elements" and "appropriate rates". Because so many streams have been modified by humans (e.g., Benke 1990), it will be difficult to find entire riverine systems that can serve as regional references, and reference reaches will have to suffice.

In the southeastern US, the Etowah River could be a candidate for a regional reference system. It is a river noted for its high biodiversity, yet it is threatened by the rapidly expanding metropolitan area of Atlanta (Burkhead et al. 1992). I shall use this river to illustrate how the questions being asked by a stream ecologist might change if a concept of stream health based on wellness were incorporated into stream research. Without such a concept, a stream ecologist might analyze the foodweb of this river, seeking to understand the relative importance of various sources of carbon, as has been done in other rivers (e.g., Meyer 1990). This research would certainly contribute to scientific understanding of stream ecosystems and would be of interest because relatively little is known about foodwebs of intermediate-sized rivers in the Piedmont region. It would be of limited relevance to assessing the health of this system because it does not include humans or their institutions. A study that would be more relevant to assessing health might include developing a model that depicts past land use and forecasts future use in the basin under different policy scenarios as has been done for forests by Wear et al. (1996). Such a study might assess the impacts of changing management policies or economic conditions on invertebrate and fish assemblages in the river and on riverine function (e.g., changes in P/R ratio). Yet even that research would be reactive not proactive and would assess stress rather than wellness.

A study based on the concept of wellness would directly involve the human forces acting in the watershed: What human actions affect the river and what groups are responsible for those impacts? How do these actions alter the capacity of the river to provide the goods and services desired by society? What groups in the community are dependent on the river, and what do they require from the river? What socioeconomic groups and what businesses benefit from a healthy river or are threatened by its degradation? What existing groups in the community are concerned about the river (e.g., is there a riverkeeper to monitor compliance)? What planning and management tools are available to maintain health (e.g., are riparian zones protected)? What are the policy tools available (e.g., are conservation easements an option)? What are the economic tradeoffs? What are the political forces that influence this river?

Answering these questions requires interaction between ecologists, economists, policy analysts, political scientists and legal scholars. This type of research also requires changes in the institutional organization of science and the way in which research contributions are evaluated by hiring and promotion committees (Risser 1996). Stream ecology has benefited from incorporation of hydrodynamic and geomorphic complexity into research designs; it is time now to integrate human and institutional complexity into stream research. This is not simply an appeal for more effective communication of research findings after the research is completed. It is a suggestion that as the research is designed, it is put it into the context of human society. Incorporating a concept of stream health in stream ecology will broaden its perspective, but need not diminish the rigor of the science.

Conclusion

Value-laden concepts like stream health offer fruitful research directions for stream ecologists who seek to contribute to the solution of environmental problems. To assess health, one must include the human component because human actions are responsible for much of the environmental deterioration. An integral concept in stream ecology over the past two decades has been that of "the stream and its valley" (Hynes 1975). This concept has served the discipline well, but it needs to be expanded to include human society and the social institutions that are an integral part of that valley. Studying land use and the effect of human activities on forests and soil erosion is necessary but not sufficient. It is also necessary to include the human institutions that interact with the stream and that control its future condition: laws and the their enforcers, management agencies, industries, conservation groups, and the culture and values of private land owners. A pristine stream in a politically unstable setting or with no supporters is not a healthy stream because it is not sustainable. The stream and human society are interdependent parts of the same system.

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Literature Cited

ANGERMEIER, P. L., AND J. R. KARR. 1994. Biological integrity versus biological diversity as policy directives. BioScience 44:690–697.

ARROW, K., B. BOLIN, R. COSTANZA, P. DASGUPTA, C. FOLKE, C. S. HOLLING, B. O. JANSSON, S. LEVIN, K.

G. MALER, C. PERRINGS, AND D. PIMENTAL. 1995. Economic growth, carrying capacity, and the environment. Science 268:520–521.

BENKE, A. C. 1990. A perspective on America's vanishing streams. Journal of the North American Benthological Society 9:77–88.

BUNN, S. E. 1995. Biological monitoring of water quality in Australia: Workshop summary and future directions. Australian Journal of Ecology 20:220–227.

BURKHEAD, N. M., J. D. WILLIAMS, AND B. J. FREEMAN. 1992. A river under siege. Georgia Wildlife 2:10–17.

GUNDERSON, L. H., C. S. HOLLING, AND S. S. LIGHT. 1995. Barriers broken and bridges built: a synthesis. Pages 489–532 *in* L. H. Gunderson, C. S. Holling, and S. S. Light (editors). Barriers and bridges to the renewal of ecosystems and institutions. Columbia University Press, New York.

HASKELL, B. D., B. G. NORTON, AND R. COSTANZA. 1992. What is ecosystem health and why should we worry about it? Pages 3–22 *in* R. Costanza, B. G. Norton, and B. D. Haskell (editors). Ecosystem health. Island Press, Washington, DC.

HYNES, H. B. N. 1975. The stream and its valley. Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie 19:1–15.

KARR, J. R. 1993. Defining and assessing ecological integrity: beyond water quality. Environmental Toxicology and Chemistry 12:1521–1531.

KARR, J. R. 1995. Ecological integrity and ecological health are not the same. Pages 97–109 *in* P. Schulze (editor). Engineering within ecological constraints. National Academy of Engineering. National Academy Press, Washington, DC.

KARR, J. R., AND T. THOMAS. 1996. Economics, ecology and environmental quality. Ecological Applications 6:31–32.

KELLY, J. R., AND M. A. HARWELL. 1990. Indicators of ecosystem recovery. Environmental Management 14:527–545.

LAMBERTI, G. A., S. V. GREGORY, L. R. ASHKENAS, R. C. WILDMAN, AND K. M. S. MOORE. 1991. Stream ecosystem recovery following a catastrophic debris flow. Canadian Journal of Fisheries and Aquatic Sciences 48:196–208.

LEWIS, W. M. 1995. Limnology, as seen by limnologists. Water Resources Update 98:4–8.

MACKAY, R. J. 1992. Colonization by lotic macroinvertebrates: a review of processes and patterns. Canadian Journal of Fisheries and Aquatic Sciences 49:617–628.

MEYER, J. L. 1990. A blackwater perspective on riverine ecosystems. BioScience 40:643–651.

MINNS, C. K. 1995. Approaches to assessing and managing cumulative ecosystem change with the Bay of Quinte as a case study: an essay. Journal of Aquatic Ecosystem Health 4:1–24.

NAIMAN, R. J., J. J. MAGNUSON, D. M. MCKNIGHT, AND J. A. STANFORD. 1995. The Freshwater Imperative: A research agenda. Island Press, Washington, DC.

NORTON, B. G. 1995. Opportunities and constraints: Toward a concept of strong ecological sustainability. Bulletin of the Ecological Society of America 76:198.

O'BRIEN, M. H. 1993. Being a scientist means taking sides. BioScience 43:706–708.

O'NEILL, R. V., J. R. KAHN, J. R. DUNCAN, S. ELLIOTT, R. EFROYMSON, H. CARDWELL, AND D. W. JONES. 1996. Economic growth and sustainability: a new challenge. Ecological Applications 6:23–24.

OXFORD ENGLISH DICTIONARY. 1971. Oxford University Press. Oxford, England.

POLICANSKY, D. 1993. Application of ecological knowledge to environmental problems: Ecological risk assessment. Pages 37–51 *in* C. Cothern (editor). Comparative environmental risk assessment. Lewis Publishers, Boca Raton, Florida.

POSTEL, S. L., G. C. DAILY, AND P. R. EHRLICH. 1996. Human appropriation of renewable fresh water. Science 271:785–788.

RAPPORT, D. J. 1989. What constitutes ecosystem health? Perspectives in Biology and Medicine 33: 120–132.

RESH, V. H., R. H. NORRIS, AND M. T. BARBOUR. 1995. Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. Australian Journal of Ecology 20:108–121.

RISSER, P. G. 1996. Decision-makers must lead in defining some environmental science. Ecological Applications 6:24–25.

ROSENBERG, D. M., AND V. H. RESH (EDITORS). 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York.

SAGOFF, M. 1992. Has nature a good of its own? Pages 57–71 *in* R. Costanza, B. G. Norton, and B. D. Haskell (editors). Ecosystem health. Island Press, Washington DC.

SCHAEFFER, D. J., E. E. HERRICKS, AND H. W. KERSTER. 1988. Ecosystem health: I. Measuring ecosystem health. Environmental Management 12:445–455.

SCHINDLER, D. W. 1987. Detecting ecosystem responses to anthropogenic stress. Canadian Journal of Fisheries and Aquatic Sciences 44 (Suppl. 1):6–25.

SCHINDLER, D. W. 1990. Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystem structure and function. Oikos 57:25–41.

SCRIMGEOUR, G. J., AND D. WICKLUM. 1996. Aquatic ecosystem health and integrity: problems and potential solutions. Journal of the North American Benthological Society 15:254–261.

SHRADER-FRECHETTE, K. 1994. Ecosystem health: a new paradigm for ecological assessment? Trends in Ecology and Evolution 9:456–457.

STANLEY, E. H., D. L. BUSCHMAN, A. J. BOULTON, N. B. GRIMM, AND S. G. FISHER. 1994. Invertebrate resistance and resilience to intermittency in a desert stream. American Midland Naturalist 131: 288–300.

STEEDMAN, R. J. 1994. Ecosystem health as a management goal. Journal of the North American Benthological Society 13:605–610.

SUTER, G. W. 1993. A critique of ecosystem health concepts and indices. Environmental Toxicology and Chemistry 12:1533–1539.

WALLACE, J. B., J. W. GRUBAUGH, AND M. R. WHILES. 1996. Biotic indices and stream ecosystem processes: results from an experimental study. Ecological Applications 6:140–151.

WEAR, D. N., M. G. TURNER, AND R. O. FLAMM. 1996. Ecosystem management with multiple owners: landscape dynamics in a southern Appalachian watershed. Ecological Applications 6:1173–1188.

WICKLUM, D., AND R. W. DAVIES. 1995. Ecosystem health and integrity? Canadian Journal of Botany 73:997–1000.

WRIGHT, J. F. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology 20: 181–197.

YOUNT, J. D., AND G. J. NIEMI (EDITORS). 1990. Recovery of lotic communities and ecosystems following disturbance: Theory and application. Environmental Management 14:515–762.

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