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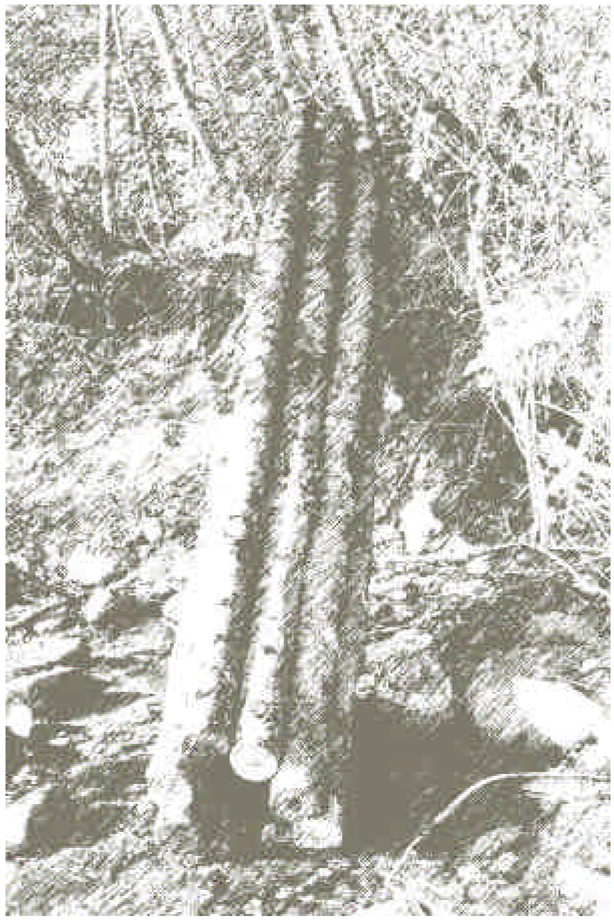

Engineered Large Woody Debris for Aquatic, Riparian and Upland Habitats

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INTRODUCTION

Over the past 100 years we have witnessed dramatic declines in salmonid populations in the Pacific Northwest. Although hatchery influences, dams, and overfishing have also played significant roles, freshwater habitat loss and degradation is acknowledged to have contributed to the decline of virtually every species of Pacific salmon in western North America (National Research Council 1996; Nehlsen, Williams, and Lichatowich 1991). One of the major long-term impacts on salmonid habitat quality has been the loss of substantial amounts of large woody debris (LWD) in stream systems. Continued loss of degradation of freshwater spawning and rearing habitat in the Pacific Northwest has serious implications for a $140 million dollar commercial salmon fishery (National Marine Fisheries Service 1990-1992 data).

Twenty-five years of research has documented the connection between forest practices and salmonid habitat loss in the Pacific Northwest (Beschta 1997; Bryant 1983; Roper, Dose, and Williams 1997). Other land uses, such as agriculture, urban, and suburban development have also caused substantial habitat loss in low elevation portions of Pacific Northwest watersheds (Beechie, Beamer, and Wasserman 1994). In response, there has been growing commitment on the part of government agencies, public interest groups, the forestry industry, and commercial and recreational fishing organizations to undo some of this damage by restoring degraded habitat in order to benefit salmonid populations and the watershed ecosystem as a whole.

Millions of dollars per year are being spent on habitat restoration and improvement projects in streams and rivers across the United States. Extensive research by geologists, aquatic biologists, hydrologists and others is providing important insight into the requirements for habitat restoration projects (Beechie and Sibley 1997; Bisson et al. 1997). City and municipal governments are including habitat projects in their capital budgets to offset the effects of development, road projects or stream channelization (Bitter and Bowers 1993). Developers are often required to create wetlands or habitat features as part of mitigation for environmental impacts (Goldberg 1997). The Electric Power Research Institute sponsored a project to quantify the loss of habitat in a Tennessee Valley Authority impacted river basin (Chen et al. 1996). Gore and Hamilton (1996) documented recent efforts to restore aquatic habitat in streams of Tennessee.

Land use impacts on upland terrestrial species are also gaining increasing attention. Wildlife habitat losses over the past century have been extensive throughout the United States. For example, Hardt and Swank (1997) studied the loss of coarse woody debris in forest lands of the Southern Appalachia. They found that downed log accumulations in old-growth forests were significantly higher than in young second-growth stands. Small mammals are dependent on downed wood for protection and habitat. Many species of birds feed on termites, ants and other insects that live on downed woody debris (Torgersen and Bull 1995).

Efforts at restoration range from trying to restore natural function to an entire watershed to attempting to stop erosion at one location within many miles of the stream network. While not always possible, an important first step of restoration is the removal or elimination of activities that are causing degradation (National Research Council 1996). We hope that restoration projects include (at a minimum) efforts to revegetate the historic flood plain so that natural recruitment of wood will eventually occur. Ideally, placement of instream wood is a bridging solution for critical habitat areas where species are facing near-term extinction. If we perform a calculation on the historic loading of wood in small streams (Bilby and Ward 1989; Bilby and Ward 1991), large woody debris restoration would require approximately 200 pieces per mile. Realistically, there are many miles of streams where natural recruitment will not be restored to anything approaching maximum capacity. Restoration in these areas will require a long term commitment to enhancement, monitoring and maintenance.

In this paper we first review current and historic efforts at rehabilitation of various types of degraded aquatic, riparian and upland habitat. We then introduce an engineered habitat structure (ELWd™) that provides an economic and viable alternative for practitioners faced with decreased availability of LWD and/or difficult sites. Finally, we describe how this innovative solution was developed using the Appreciative Design process (Dooley and Fridley 1996).

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HABITAT IMPROVEMENT

Efforts to improve stream habitat date from the early 1900's (Hubbs, Greeley, and Tarzwell 1932; White 1996). The most common methods to improve or manage in-stream habitat and/or hydrology include current deflectors, low-head dams, weirs, planted vegetation and boulder placement (Gore and Hamilton 1996). Placement of LWD is a relatively recent advancement, driven by a recognition that LWD provides many previously under-appreciated functional values (Bilby and Ward 1991). As more experience with woody debris is gained by practitioners, a number of technical questions are emerging that transcend the boundaries of particular projects and streams.

Because of decreased availability of LWD and high expense for placement, logs of intermediate size (25 - 50 cm diameter), with or without root wads attached, are placed in the stream and anchored to the bedrock or anchor rocks with steel cables. Cabling is necessary to prevent the relatively light logs from being washed downstream where they might collect in log jams or against public structures. This approach has a number of limitations. First, the logs used are otherwise merchantable and have significant value to mill owners and log brokers. Second, moving and placing the logs requires heavy equipment or cable systems. Third, the required steel cabling is expensive to install and adds a very unnatural element to the landscape.

LWD supply is limited as evidenced by rapidly escalating prices to restoration contractors and landowners. The large piece size and required access for cranes and heavy equipment is limiting operational practice of stream enhancement to a small fraction of potential stream-miles. If an engineered solution could be crafted that was cost-competitive with native LWD, of relatively unlimited volumes, and could be placed by crews working with limited equipment in remote sites, then a ready demand should exist in many regions of the United States and Canada. The ideal solution for an engineered alternative to LWD would be made of native organic materials that are machined and assembled such that the pieces and debris blend with the natural environment when the engineered LWD inevitably breaks up in a flood or degrades with time.

WARMWATER STREAM HABITATS

Analysis of the literature provides a number of clues about design requirements and constraints for engineered habitat features in warmwater streams of the southeastern U.S. Benke and Henry (1985) studied the importance of wood snags as habitat in the Satilla River in southeastern Georgia. Benke and Henry found that snags were the dominant source of invertebrate organisms caught in drift samples. Major warmwater fish species obtained at least sixty percent of their food from snag-related organisms. One clue about the properties of woody debris that is beneficial to insect colonization comes from Phillips (1996). Phillips found that many species of aquatic insects do not exhibit a preference for habitat type. However, *Corydalus cornutus* showed a significant preference for wood with advanced decay and for wood with rough-textured bark. From these findings we can conclude that engineered woody features would benefit from high surface area since the production of aquatic invertebrates is a function of organic surface area. Also, we can conclude that within a stream reach more wood is better than less wood.

Ebert, Nelson and Kershner (1991) studied fish habitat in sixteen Louisiana streams. They found that pools formed by woody debris were associated with the majority of fish species. Habitat diversity was associated with the interaction of channel slope, soil type and woody features. The authors were not focused on the woody elements so give few clues about functional requirements and constraints that would affect engineered elements. Marzolf (1978) reports that removal of snags from warmwater rivers also removes fish cover and shelter. Neither Benke & Henry nor Marzolf provide any direct clues about the ideal physical properties of snags – either natural or engineered.

Rootwads (stumps with roots attached) contain less merchantable wood and thus are relatively easier to acquire than large woody debris for stream restoration projects. Ketchem (1997) evaluated the effectiveness of rootwad revetments as a low cost alternative for Natural Resources Conservation Service (NRCS) projects in Virginia. Ketchum found that rootwads with boles attached were modestly effective for stream bank protection and provided habitat values, but were not appropriate for sites where aesthetics were important.

COLDWATER STREAMS FOR RESIDENT TROUT

There are a number of suggestions in the literature that woody debris habitat requirements for resident trout populations may be different than the requirements for salmon in coastal streams. Culp et. al. (1996) found that rainbow trout fry seek fine woody debris rather than large accumulations of coarse wood. The authors speculate that accumulations of large wood attract predatory adults who feed on the fry. Culp and his co-authors constructed woody structures from milled lumber. The structures were effective, but the square edge wood and generally blocky structure would appear very unnatural in a wildland stream environment. The results of their study suggest that an engineered woody structure could be made to conform with the ELWd™ concept by using small diameter logs and creating many small internal passages. Functional requirements would include a high surface area and openings scaled to trout fry. Constraints would include ensuring openings were sufficiently small to prevent predatory adults from entering the structure, and ensuring the aesthetic requirements are met. The functional requirements and constraints would need to be reduced to technical terms. Maximum and minimum openings must be specified in centimeters or inches.

Fausch et. al. (1995) looked at the role of large wood in pool formation in six Colorado mountain streams. They found that pool forming logs typically were of larger diameter than other wood along the stream and were lodged perpendicular to the flow, creating plunge pools. For engineered woody debris, the findings of Fausch et. al. suggest that log length would need to be established via a stream survey where channel widths were measured. Engineered log diameters would also be established to achieve a desired plunge pool step heights. We may find that an the ELWd™ structure should be some shape other than round. Flebbe and Dolloff (1995) explored the role of woody debris in trout streams of North Carolina. They found that rainbow and brown trout were found most often in streams having large amounts of large woody debris. They also found that stream reaches in old growth forests held wood of larger diameter than reaches in second-growth timber stands. The authors conclude that if we are to restore trout habitat to pre-settlement conditions we will need to add amounts and sizes of woody debris that are more typical of those found in old growth forests.

Wallace, Webster and Meyer (1995) studied the effects of adding large woody debris to a mountain stream in North Carolina. They found that, when logs were added at the downstream end of riffles, the relative populations of aquatic insects changed dramatically. The logs tended to increase stream depth and decrease current velocity. Fine sediment was trapped behind the log additions. The author's observations suggest that careful thought go into the planning of woody debris additions and ongoing monitoring be budgeted to determine if the intended effects are obtained.

Myers and Swanson (1996) have extensively studied the effectiveness of alternative methods to restore degraded streams in Nevada. The amount of coarse woody debris was highly correlated with pool quality and quantity. The habitat value of coarse woody debris related pools was particularly evident during low flow periods. Woody debris had historically been removed from the study streams apparently to improve conveyance. The authors recommend that woody debris be restocked in the streams. They do not provide guidance on the species, diameter or length of wood to be collected.

CONSTRUCTED AND ENHANCED NATURAL WETLANDS

Mitsch (1992) observes that natural riparian wetlands have almost been eliminated from the United States. Among the many roles that wetlands play in the landscape is the important role of providing habitat for wildlife. Mitsch is active in a program to construct wetlands to improve water quality and to recover some of our nation's lost wetland reserves. Ogden (1991) explored the habitat needs of wood storks (*Mycteria americana*) to attempt to understand why the population was increasing in Florida. Ogden found that artificial wetlands and altered wetland sites contributed to the amount of nesting habitat available to the storks. There are a number of major constructed and enhanced wetland projects in Florida. It is unknown whether woody elements are considered in the design phase of such projects; however, woody stumps and partially submerged logs are known to be part of the natural wetland environment.

The role of decaying wood in riparian wetlands is not well understood. Polit and Brown (1996) studied the contribution of dead wood to the nutrient budget of a floodplain forest in Illinois. They found that 41 percent of the dead wood on the site was downed logs in various states of decomposition. Downed wood accounted for over half of the nitrogen and phosphorous pools, and nearly 70 percent of the potash pool. In the forest studied by Polit and Brown downed wood amounted to 6.6 Mg per hectare. These findings suggest that constructed wetlands should be "charged" with large amounts of woody debris as part of the construction project.

LAKESHORE HABITATS

Christensen et. al. (1996) studied the effect of human activity on coarse woody debris near the shoreline of temperate lakes. In undeveloped lakes they found an average of over 850 logs per mile of shoreline compared to less than 100 logs per mile of shoreline in developed lakes with cabins along the shore. Near-shore coarse woody debris is important habitat for fish and other aquatic organisms. The authors recommended new regulations to minimize additional loss of coarse woody debris, but did not appear to consider ways to restock seriously impacted lakes with woody habitat features. Since Christensen et al. studied sixteen lakes in detail, they should have useful insight about the functional requirements and constraints that would have to be met by any engineered large woody debris product.

UPLAND HABITAT

In a study in the Southern Appalachian range, Hardt and Swank (1997) concluded that downed log accumulations are lowest in managed forests and highest in old growth forests. Restoration of some upland habitats may require addition of downed logs of size and properties similar to those found in old growth forests. Logs with cavities are highly desired. It would be useful to survey the old growth stands studied by the authors and catalog the diameter, length and condition (hollows, etc.) of downed logs.

The pileated woodpecker, a Management Indicator Species in the USDA Forest Service management guidelines, is dependent on forest-dwelling ants for much of its food supply (Torgersen and Bull 1995). In northeastern Oregon the pileated woodpecker preys on ants that colonize downed logs. It is plausible that engineered log structures could be designed to optimize the production of wood-dwelling ant species, hence providing additional food for the woodpecker. Torgersen and Bull use this example to point out the complex interaction of downed wood and organism inhabiting forested landscapes.

DESIGN OF IN-STREAM ELWd™ STRUCTURE USING APPRECIATIVE DESIGN METHOD

Although we have identified many areas of opportunity for improving habitat, the balance of this paper will focus on the design and development of and engineered alternative to native large woody debris for use in streams of the Pacific Northwest. As we discussed at the outset, there is a tremendous need for rehabilitation and enhancement of rivers and streams of northern California, Oregon, Idaho, Washington and British Columbia.

The Appreciative Design process (Dooley and Fridley 1996) was followed to create a LWD solution that may be preferred for many stream, wetland, lake and upland situations. Appreciative Design is a structured process to search for a best set solution to technical and organizational problems. The Appreciative Design process is a significant extension of the hierarchical axiomatic design methodology of Suh (1990; 1995a) and includes many features of the Soft Systems Methodology developed by Checkland (1990).

Suh's structure and optimization methods (Suh 1990) (Suh 1995b) are particularly well suited for addressing the messy problems that are common in industry and the natural resource fields. Suh's approach is based on a set of design rules. Our implementation of Suh's approach adds some important structure and detail, as well as provides an easily followed hierarchical tracking of information, alternatives and decisions. The hierarchical structure allows reviewers, decision-makers and others to easily follow the history of decisions made throughout a project.

Suh's design principles are expressed in terms of a decision logic that includes *functional requirements, design parameters* and *constraints* (Suh 1990). Functional requirements (FRs) are design objectives cast in solution-neutral and independent statements. There is general consensus that problems are best defined when the objectives are framed by what is to be achieved by the project rather than by how needs are to be met (Love 1980).

Design Parameters (DPs) are either brainstormed alternatives or calculated specifications that become features of a solution. Brainstorming, ideation and other methods of creating or searching for alternative solutions are well understood by engineering professionals, educators and students so did not need to be included in the model.

Constraints (Cs) are objective statements and mathematical relationships that set bounds on the range of DPs that are acceptable. Constraints provide limits on the how, what, when, where and why of the design solution. Constraints are most often used by designers as criteria to sort alternative DPs into those which are acceptable and those to be discarded or reworked. An initial set of constraints typically is drawn from conversations with the client and all relevant stakeholders. Constraints can also be found through exploration of the laws of nature (e.g., $f = ma$, $\sigma = mc/I$), laws of humankind (e.g. codes, laws and regulations), cultural norms of the organization (e.g., policy and design manuals), and norms of the community (e.g., codes of ethics). In all cases constraints must be linked to a "constraint owner" in order to make them relevant to the problem at hand (McIntyre and Higgins 1989). The constraint-owner linkage provides relevance to a constraint and its source.

The problem of designing large woody debris alternatives begins with a careful discovery and listing of the functional requirements that native large woody debris provides to an aquatic environment. The function of LWD includes the following characteristics:

1. Interrupt the stream flow to trap coarse sediment upstream of the LWD to create bars or islands (Abbe and Montgomery 1996)
2. Modify stream flow to create pool structure downstream of LWD (Cherry and Beschta 1989)
3. Direct high-water flow to support hydraulic routing (Gippel 1995) (Gregory and Bisson 1997)
4. Trap and hold small organic materials (leaves, needles, carcasses, etc.) (Culp, Scrimgeour, and Townsend 1996)
5. Provide hydraulic roughness to the stream during high flow conditions (Abbe and Montgomery 1996)
6. Provide habitat and perches for aquatic insects, amphibians, birds and riparian mammals (Borchardt 1993)
7. Provide structure and nutrients for microbiological organisms important to the aquatic ecosystem (Bilby and Ward 1989)
8. Provide long term support for aquatic and semi-aquatic plant communities by providing crags and silt traps within the structure
9. Provide a continuing flux of organic carbon and decay products to a stream system (Chessney, Per. Comm)

In order to perform these functional requirements an engineered LWD solution would be subject to physical parameter constraints such as the following:

1. Cross-section and length are proportional to stream channel width and depth (Beechie and Sibley 1997; Bilby and Ward 1989)
2. Mass, specific gravity or other features to keep LWD in place during all but most severe flows (heavier is better)
3. High hydraulic roughness (higher drag is better)
4. High physical surface roughness to trap sediments, debris, etc. (rougher is better)
5. Maximum surface area (more surface area per unit volume is better)

In addition to physical parameter constraints there are a number of stakeholders who contribute constraints to the design process. Such stakeholders are termed “constraint owners.” Early in our development process we began a dialog with various stakeholders to identify their needs and translate needs into top level design constraints. The dialog continues as we refine our designs and create physical models for review and comment.

Client Constraints

- Competitive installed cost compared to native LWD
- Low cost for placement (less equipment rental cost is better)
- Lasts long time (lower maintenance cost is better) (lasts until riparian silviculture begins to deliver)
- Applicable to sites with difficult access for large equipment (install with hand crews is better)
- Does not increase risk of damaging downstream resources (lower risk of damage claim is better)

Fisheries Enhancement Contractor Constraints

- Manufacture from readily available materials (smaller diameter components is better)
- Low tech manufacture (product value does not warrant expensive manufacturing process)
- Easy to train crews to install (lower information content is better)
- Minimize risk liability claim from high water failure (less risk of damage to property & public works)

Volunteer Coordinator Constraints

- Maximum number of structures per grant dollar (lower requirement for rental equipment and operators is better)
- Need to separate volunteers from mechanized equipment operations (install with all hand labor is best)
- Maximize volunteer participation in meaningful part of projects (volunteers putting structures in stream is better than volunteers doing cleanup after machines do the habitat work)
- Easy logistics to prepare for volunteer events and work days (stage kits of lightweight materials is better)

Environmental and Recreational Special Interests

- Materials are all organic and similar to native materials
- Avoid steel, plastics and other unnatural materials
- Structures look like they belong in the natural environment (better aesthetics)
- Debris from failed structures looks natural in the streamside environment

Materials Supplier Constraints
- Utilize non-merchantable or low value raw materials
- Utilize readily available raw materials

Regulator and Public Agency Constraints
- Amenable to meeting the requirements of WAC 220-110
- Natural materials (no car bodies, concrete, tires, asphalt, etc.)
- Does not increase flood height (less flood impact is better)
- Does not increase risk to public works (bridges & culverts) over native LWD risks (lower risk is better)

We can now use the starting functional requirements and constraints to begin a formal ideation and invention activity following the Appreciative Design process model. The current design of our engineered large woody debris is an “optimal” solution to the design problem as we characterized it.

FEATURES OF THE ELWd™ HABITAT MATERIAL FOR PACIFIC NORTHWEST SALMONIDS
ELWd™ structures (pronounced “elwood”) are engineered alternatives to native large woody debris. Structures are assembled on site from small diameter poles or logs to make large diameter woody structures that satisfy the functional requirements of native large woody debris. **T**he fundamental element of ELWd™ structure is to create a hollow cylinder by assembling even numbers (pairs) of small diameter logs into a tube or truncated cone. It is possible to manufacture ELWd™ structural components in the field with portable power and hand tools. However, we recommend that structural components be regionally manufactured and delivered to project sites as kits.

The central cavity inside the ELWd™ structure can be filled with cobbles or gravel to decrease buoyancy, increase effective specific gravity, and help the structure stay in place during high water and floods. Stones may be collected locally by the crew that is installing the ELWd™ structure. A novel design and method to attach root structures to the tubular ELWd™ structure has also been developed. Engineered roots will improve the aesthetics of structures while they significantly improve anchoring in gravel or cobble streams.




Figure 1 a,b,c,d. A small model was used to prove the concept of building large diameter structures from pairs of small diameter logs. A full-scale prototype was fabricated from forest residuals using a mix of western red cedar, hemlock, alder and Douglas fir logs.

STATUS

Invention of the ELWd™ structure occurred late in 1996. A US patent application was filed late in the spring of 1997 and foreign applications are now pending as well. During the summer 1997 habitat project season we refined our design and spent considerable time visiting project sites to further understand stakeholder needs.

Among the identified needs was scientific data on performance of engineered large woody debris in comparison to native large woody debris of similar size. Toward that end we entered into a cooperative research program with the Center for Streamside Studies (CSS) at the University of Washington. The CSS has attracted additional funding from other companies to fund a forest hydrology MS student. The research plan calls for us to install fifteen structures across three study sites during the summer of 1998. The CSS study will evaluate functional performance of engineered large woody debris versus native large woody debris in side-by-side trials.

We are also pursuing commercial opportunities in relatively benign streams. One licensee is now on board and actively marketing structures in a portion of Washington State. ELWd™ structures have been designed and fabricated up to twenty-four feet long and twenty-eight inches in diameter for use in salmonid streams around the Puget Sound region.

The primary focus for the balance of the 1998 season is to install demonstrations and research projects with governmental agencies and large potential customers. By the end of 1998 we will begin to seek cooperators in agencies and universities across North America to begin development and evaluation of ELWd™ structures for upland, wetland, lake and warm-water habitats

REFERENCES

Abbe, Timothy B., and David R. Montgomery. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. *Regulated Rivers Research & Management* 12:201-221.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. *North American Journal of Fisheries Management* 14:797-811.

Beechie, T.J., and T.H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. *Transactions of the American Fisheries Society* 126 (2):217-229.

Benke, A.C., R.L. Henry, D.M. Gillespie, and R.J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. *Fisheries* 10 (5):8-13.

Beschta, Robert L. 1997. Restoration of riparian and aquatic systems for improved aquatic habitats in the upper Columbia River Basin. In *Pacific Salmon and Their Ecosystems: Status and Future Options*, edited by D. J. Stonder, P. A. Bisson and R. J. Naiman. New York: Chapman and Hall.

Bilby, R.E., and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. *Transactions of the American Fisheries Society* 118:368-378.

Bilby, Robert E., and James W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. *Canadian Journal of Fisheries and Aquatic Science* 48 (2499-2508).

Bisson, P. A., G. H. Reeves, R. E. Bilby, and R.J. Naiman. 1997. Watershed management and Pacific salmon: Desired future conditions. In *Pacific Salmon and Their Ecosystems: Status and Future Options*. New York: Chapman and Hall.

Bitter, Susan D., and Keith J. Bowers. 1993. Wetland mitigation and stream restoration. *Public Works* 124 (11):50-52.

Borchardt, Dietrich. 1993. Effects of flow and refugia on drift loss of benthic macroinvertebrates: implications for habitat restoration in lowland streams. *Freshwater Biology* 29:221-227.

Bryant, M.D. 1983. The role and management of woody debris in west coast salmonid nursery streams. *North American Journal of Fisheries Management* 3 (3):322-330.

Checkland, P., and J. Scholes. 1990. *Soft Systems Methodology in Action*. Chichester: Wiley.

Chen, C.W., J. Herr, R.A. Goldstein, F.J. Sagona, K. E. Rylant, and G.E. Hauser. 1996. Watershed risk analysis model for TVA's Holstron River basin. *Water Air and Soil Pollution* 90 (1-2):65-70.

Cherry, J., and R.L. Beschta. 1989. Coarse woody debris and channel morphology: a flume study. *Water Resources Bulletin* 25 (5):1031-1036.

Christiansen, D.L., B.R. Herwig, D.E. Schindler, and S.R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. *Ecological Applications* 6 (4):1143-1149.

Culp, Joseph M., Garry J. Scrimgeour, and Greg D. Townsend. 1996. Simulated fine woody debris accumulations in a stream increase rainbow trout fry abundance. *Transactions of the American Fisheries Society* 125:472-479.

Dooley, James H., and James L. Fridley. 1996. Appreciative Design: incorporating social processes into engineering design. Paper 965004. St. Joseph, MI: ASAE.

Ebert, D.J., T.A. Nelson, and J.L. Kershner. 1991. A soil-based assessment of stream fish habitats in coastal plains streams. Paper read at Warmwater Fisheries Symposium 1, June 4-8, at Scottsdale, AZ.

Fausch, K.D., C. Gowan, A.D. Richmond, and S.C. Riley. 1995. The role of dispersal in trout population response to habitat formed by large woody debris in Colorado mountain streams. *Bulletin Francais de la Peche et de la Pisciculture* 337-9:179-190.

Flebbe, P.A., and C.A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian wilderness streams of North Carolina. *North American Journal of Fisheries Management* 15 (3):579-590.

Gippel, Christopher J. 1995. Environmental hydraulics of large woody debris in streams and rivers. *Journal of Environmental Engineering* 121 (5):388-395.

Goldberg, Carol. 1997. Living options good for seniors, economy. *LI Business News* 1997 (20):23-24.

Gore, James A., and Steven W. Hamilton. 1996. Comparison of flow-related habitat evaluations downstream of low-head weirs on small and large fluvial ecosystems. *Regulated Rivers Research and Management* 12 (459-469).

Gregory, S.V., and P.A. Bisson. 1997. Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. In *Pacific Salmon and Their Ecosystems: Status and Future Options*, edited by J. J. Stouder, P. A. Bisson and R. J. Naiman. New York: Chapman and Hall.

Hardt, R.A., and W.T. Swank. 1997. A comparison of structural and compositional characteristics of southern Appalachian young second-growth, maturing second-growth, and old-growth stands. *Natural Areas Journal* 17 (1):42-52.

Hubbs, Carl L., John R. Greeley, and Clarence M. Tarzwell. 1932. *Methods for the Improvement of Michigan Trout Streams. Bulletin No. 1 of the Institute of Fisheries Research*. Ann Arbor, MI: University of Michigan Press.

Ketchem, Alica J. 1997. The use of rootwad revetments in emergency and nonemergency streambank restoration. Paper 972139. St. Joseph, MI: ASAE.

Love, S.F. 1980. *Planning and Creating Successful Engineering Designs*. New York: Van Nostrand Reinhold Co.

Marzolf, G.R. 1978. *The potential effects of clearing and snagging on stream ecosystems*. Washington, D.C.: U.S. Department of Interior, Fish and Wildlife Service.

McIntyre, S.C., and L.F. Higgins. 1989. Embedding stakeholder analysis in object oriented organizational modeling. In *Proceedings of the Twenty-Second Annual Hawaii International Conference on Systems Science. Vol. III. Decision Support and Knowledge Based Systems Track*, edited by R. Blanning and D. King.

Mitsch, WIlliam J. 1992. Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution. *Ecological Engineering* 1:27-47.

Myers, T.J., and S. Swanson. 1996. Long-term aquatic habitat restoration: Mahogany Creek, Nevada, as a case study. *Water Resources Bulletin* 32 (2):241-252.

National Research Council. 1996. *Upstream: Salmon and Society in the Pacific Northwest*. Washington, DC: National Academy Press.

Nehlsen, W.J., J.E. Williams, and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* 16 (2):4-21.

Ogden, J.C. 1991. Nesting by wood storks in natural, altered, and artificial wetlands in central and northern Florida. *Colonial Waterbirds* 14 (1):69-45.

Phillips, E.C. 1996. Habitat preference of large predatory aquatic insects (megaloptera and odonata) in Ozark streams of Arkansas. *Texas Journal of Science* 48 (4):255-260.

Polit, J.I., and S. Brown. 1996. Mass and nutrient content of dead wood in a central Illinois floodplain forest. *Wetlands* 16 (4):488-494.

Roper, Brett B., Jeffrey J. Dose, and Jack E. Williams. 1997. Stream restoration: Is fisheries biology enough? *Fisheries* 22 (5):6-11.

Suh, N.P. 1990. *The Principles of Design*. New York: Oxford University Press.

Suh, N.P. 1995a. Axiomatic design of mechanical systems. *Transactions of the ASME* 117:2-10.

Suh, N.P. 1995b. Design and operation of large systems. *Journal of Manufacturing Systems* 14 (3):203-213.

Torgersen, T.R., and E.L. Bull. 1995. Down logs as habitat for forest-dwelling ants - the primary prey of pileated woodpeckers in northeastern Oregon. *Northwest Science* 69 (4):294-303.

Wallace, J. Bruce, Jackson R. Webster, and Judith L. Meyer. 1995. Influence of log additions on physical and biotic characteristics of a mountain stream. *Canadian Journal of Fisheries and Aquatic Science* 52 (2120-2137).

White, Ray J. 1996. Growth and development of North American stream habitat management for fish. *Canadian Journal of Fisheries and Aquatic Science* 53:342-363.