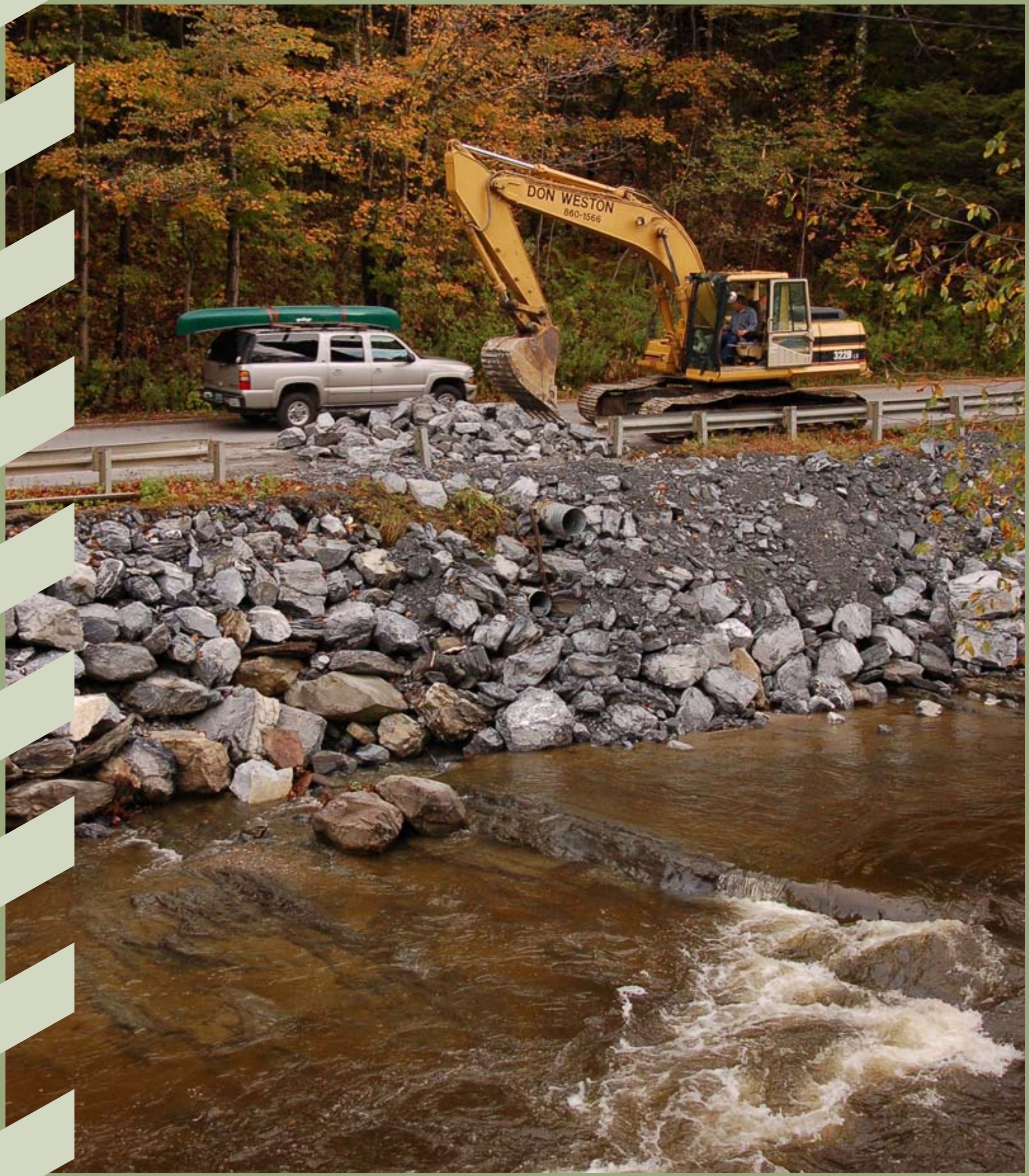

Integrating Recreational Boating Considerations Into Stream Channel Modification & Design Projects

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AW AMERICAN WHITEWATER

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1 | Introduction

Stream channels are modified to meet a wide range of social and ecological goals. Many small-scale projects that involve adding wood and rock to rivers and their banks are aimed at improving fish habitat or protecting riparian property. Other projects are much larger in scale, such as those aimed at restoring a functional river channel in sites previously impacted by dams, mining, development, or other industrial-scale impacts.

Many of the rivers where these projects are carried out attract significant recreational use. Anglers ply virtually all waters in the United States, and each year kayakers and canoeists descend virtually every stream, including those that even rarely have enough water to float a kayak. Adults and kids alike often take a swim in rivers, or simply walk along them and take in the vistas of flowing water. This diverse recreational use is a vital component of the quality of life and economies of many communities.

While most stream modification projects have well-defined primary ecological or engineering goals, this paper offers advice for integrating (often secondary) recreational goals into project design and implementation. Integrating recreational goals and safety into projects can foster public support for projects, encourage recreational use and stewardship, and reduce the likelihood of avoidable accidents.

This paper aims to offer stream modification practitioners simple advice on how to create projects that meet their primary objectives while ensuring the projects are relatively low-risk and enjoyable for people descending the stream in canoes, kayaks, and rafts. Since swimming is an unavoidable component of paddling rivers, the recommendations in this paper will also provide safety benefits not only for paddlers, but also for hikers, anglers, and other recreationists that intentionally or accidentally swim in a project area. This paper offers no guarantees of public safety, but rather common sense practices for lowering recreational risks based on recreational experience.

This paper is intended for use by anyone planning to add or remove material (typically rock and wood) from a stream, or otherwise change a stream's shape or function. Applicable projects include stream restoration or enhancement projects, road and infrastructure projects that encroach on stream channels, and flood clean-up and prevention efforts.

Figure 1.1 | *Virtually all streams are enjoyed by paddlers, anglers, and other recreationists, even small intermittent streams.*

2 | Consultation and Review

While this guide is intended to give channel designers a working knowledge of recreational considerations, this knowledge is no substitute for consulting with the recreation community. Recreationists, many of whom are knowledgeable and often deeply concerned with a specific river or regional rivers, can offer valuable insight into channel design projects. The importance and value of outreach to the recreation community can't be overstated. Recreationists can confirm the types and amounts of existing and potential use, can highlight existing features of importance, and can offer input on the safety and desirability of designs throughout the design and construction process. Recreationists – who typically appreciate complex and healthy rivers – can also provide media, political, and volunteer support for well-designed projects.

To find appropriate recreationists for consultation, it is recommended that at a minimum regional paddling and angling clubs and businesses are contacted. American Whitewater can provide assistance with making these contacts as needed, and Trout Unlimited is also an excellent resource for coldwater streams.

3 | Channel Design and Recreational Risk

Paddling rivers, like all activities, carries some level of inherent risk. These risks are determined by the features in the streambed, the volume of flow, the recreational activity, and the skill and equipment of the recreationists. People choose to expose themselves to calculated risks based on their knowledge of those risks and the anticipated rewards of the endeavor. Risks are calculated based on a foundation of experience with other rapids and rivers.

This foundational knowledge is based primarily on past experience navigating logs, rocks, meanders, and other river features that were arranged by the natural forces of the river into generally predictable patterns. Based on the public expectation that rivers and specific river features will follow natural patterns, channel design that mimics natural patterns can enhance public safety.

With this said, natural rivers possess features that range from physically impossible to survive to features that are so compelling people will travel thousands of miles to experience them. This paper describes the full spectrum of natural features, from death-trap to recreational-treasure, and offers advice on how to avoid the former and create the latter, while still meeting the project's primary objectives. Successful channel designs will incorporate features that range from benign to extremely appealing to recreationists, while creating no unnecessary objective hazards.

4 | Recreational Hazards and Associated Features

Paddlers move down rivers in small groups, stopping occasionally in eddies and pools to rest, regroup, and peer downstream. Often, by "eddy-hoping" down the river, paddlers can see enough of the rapids downstream to pick their route. Paddlers call this "boat scouting." When faced with a horizon line or blind corner, paddlers typically catch an eddy, and walk down the shore to scout the rapid prior to running it. Sometimes they won't like what they see and they will either choose an easy route if one exists, or portage around the rapid on shore.

All the while, paddlers are visually scanning the river for three things, which are, in order of decreasing priority: hazards to be avoided, a safe and personally navigable route, and fun to be had. It is important for channel designers to understand and recognize the features and factors that result in hazards, reasonable passage, and fun. The following table describes river features that are objective hazards (e.g. especially and clearly hazardous features) that paddlers actively avoid. Anglers, swimmers, novice floaters and some other river recreationists may be less expert at recognizing these river hazards, however these features are similarly hazardous to all recreationists that find themselves moving downstream in the flow, with or without a boat beneath them.

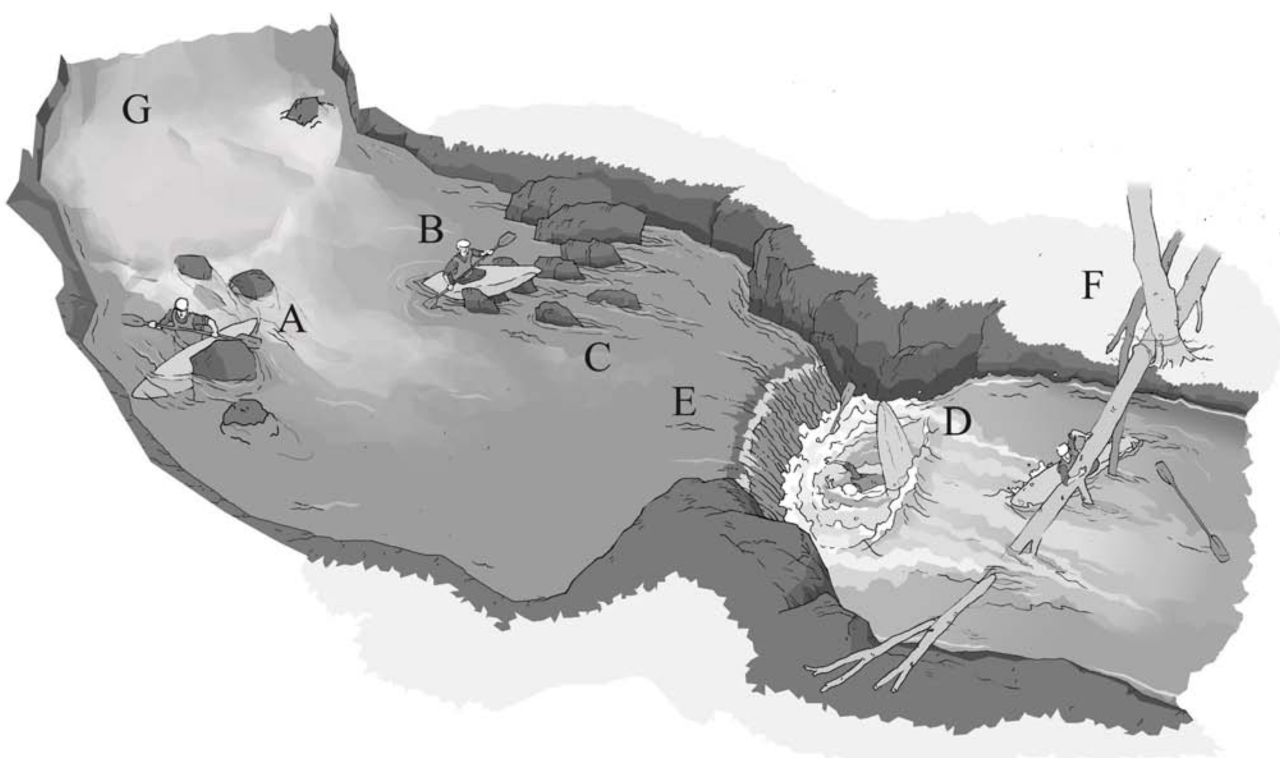
It should be noted that these risks increase in severity with gradient (channel slope) and water velocity. Objective hazards in low gradient streams however still pose a risk – it is astounding how much force even slow currents can exert on a paddler or swimmer entrapped by sharp or undercut rocks, wood, or debris.

While the objective hazards described above and the desirable features to follow this section are relatively easy to define regardless of where they occur, the factors that make a rapid personally navigable for paddlers are a bit more complicated and subjective. The best way to consider this issue is by using the International Scale of River Difficulty (see Appendix 1), which describes in some detail the level of challenge and complexity associated with individual rapids. Channel designers should seek to create the same classification of rapids that existed in the river reach prior to disturbance. Ideally, remnant features will give significant clues to the structure of the historic river bed. If no historical information is available, reference reaches with similar channel slope, substrate size, and flow should be used. Lastly, there may be recreational (e.g. social) goals that arise in the scoping and permitting process for a channel design project that may also be considered.

Figure 4.1 | Objective Hazards and their Associated Recreational Concerns

HAZARDOUS FEATURE	RECREATIONAL CONCERN
A. Rocks or wood with water flowing under them	**Entrapment:** Individual undercut rocks, porous rock combinations, single logs, or log accumulations are highly likely to entrap, above or below water, a paddler or swimmer encountering them.
B. Rocks or wood vertically oriented and in swift current	**Entrapment and/or Impact:** If a person or boat washes up against a vertically oriented rock or log in swift current their boat or body may be pinned, at times under water.
C. Sharp rocks in swift current	**Impact and Entrapment:** Sharp rocks can break boats, injure swimmers, and are more likely to pin a boat or person underwater.
D. Large symmetrical hydraulics (holes) difficult or impossible to move through or escape	**Flush Drowning, Injury, or Gear Loss:** Large holes can hold boats and/or swimmers. Swimmers may drown in the hole or may be exhausted and encounter problems as they flush downstream. Shoulder injuries are common. Gear loss is common upon swimming.
E. Drops or swift current with obstructions immediately downstream	**Impact and Entrapment:** Paddlers may careen (e.g. "piton") into rocks or logs immediately below drops with their boats, which can result in injury. Vertical pins or other forms of entrapment are possible. Swimmers may be pinned or injured.
F. Cable, rope, chain, rebar, metal debris, or any man-made structure	**Entrapment:** Rope and cable are extremely capable of trapping a swimmer under water. Wooden and metal structures can entrap paddlers like A-C above, a function exacerbated by a snagging hazard associated with nails, bolts, etc.
G. Long sections of rapids with no visible eddies	**Flush Drowning or Objective Hazards Beyond Sight Distance:** A lack of eddies or pools deny swimmers shore access, which can lead to flush drowning. It can also deny paddlers the ability to eddy out above an objective hazard (e.g. A-F above).

Figure 4.2 depicts each of these dangerous river features. | *Objective hazards described in Figure 4.1 are illustrated below in Figure 4.2: undercut rocks (A), vertical rocks (B), sharp rocks (C), symmetrical keeper hydraulics (D), obstructed drops (E), cabled and/or spanning logs not in contact with the substrate (F,A), and long rapids lacking eddies (inferred at G).*



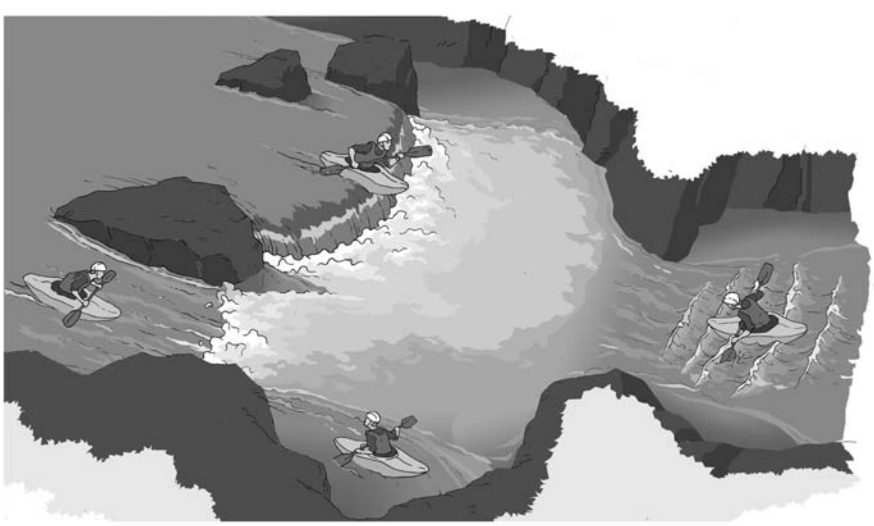
5 | Recreational Boating Goals and Associated Features

Of course, navigating a river reach is about more than safely passing from point A to point B. Along the way, paddlers often encounter rapids and features that dish out aesthetic, thrilling, and fun descents. Paddlers seek rapids that have “clean lines” (a “line” is a route) through rapids that lack shallow rocks and objective hazards. They seek features that provide opportunities to perform specific techniques that are fun and challenging, like catching eddies, boofing drops (i.e. ramping with speed to land flat), punching holes, surfing, etc. Rapids that feature textbook opportunities for these maneuvers have high value to the paddling public.

Figure 5.1. | Desirable Features and Their Recreational Attributes

DESIRABLE FEATURE	RECREATIONAL ATTRIBUTE
A. Deep pools between rapids	Resting and rescue for paddlers. Low risk fishing and swimming.
B. Vertical drops of any height with a relatively sharp 90 degree lip.	Paddlers can “boof” such drops resulting in a flat landing. Flat landings help paddlers avoid the hydraulic and any underwater hazards at the base of the drop, and are fun.
C. Drops with lateral eddies immediately adjacent and downstream of the lip, and with rounded rocks forming the edge of the lip.	Paddlers can also “boof” into eddies, using either lateral rocks at the lip or pillows of water next to such rocks as a ramp to provide lift, resulting in short freefall and a flat landing in the eddy.
D. Waves	Waves are formed by compression of flow, gradient, and bed roughness and/or entry into a deep pool. They are fun to paddle over, and waves of specific shapes and sizes can be surfed by kayakers, just like stationary ocean waves.
E. Holes (also called hydraulics)	Holes are formed by water flowing fast over a downward sloping rock, creating surface backwash. The backwash of most holes can be safely “punched” through by paddlers, providing excitement and challenge. Some holes form highly desirable freestyle surfing opportunities. Such holes generally have lateral eddies, gently sloping lead-ins (<30 degrees), and deep water immediately beneath and down-stream of them.
F. Eddies	Eddies are calm or upstream flowing areas downstream of objects. They provide rest, safety, and added complexity for paddlers. They also provide good fish habitat and thus good angling. Ensuring that rapids have eddies throughout them and below makes rapids recreationally better.
G. Slides	Sloping water slides less than 30 degrees of any height are fun for paddlers, offering fast flow and typically a hydraulic to punch through. Asymmetries and lateral eddies improve safety and enjoyment.
H. Slots	Several large rocks at the lip of a drop of any height form “slots” where water pours between them and over the drop. Multiple and diverse routes occur which paddlers enjoy.

Figure 5.2 depicts a river channel with each of the eight desirable features described above. | Desirable paddling features described in Figure 5.1 are illustrated in Figure 5.2: The top paddler is boofing a **vertical drop** *over a* **hole** *with low retentive power, into a* **deep pool.** *The top paddler could have gone farther to his left into a lateral* **eddy.** *The left paddler is running a* **slide** *through a* **slot***, and will need to punch through the mildly retentive* **hole** *just downstream. The lower paddler is resting and setting safety in an* **eddy***. The right paddler is surfing a* **wave** *with lateral* **eddies** *next to it.*



6 | Wood Structure Guideline

Wood poses a significant hazard for people paddling or swimming in the flow of a river. People and boats can become pinned against logs in even slow current, can become entrapped between a log and the substrate, can become snagged on branches, or become entrapped in log jams. Not only can this happen – it often does. According to American Whitewater's paddling accident database[1] and associated reports, wood is among the leading factors contributing to paddling deaths.

The chance of a person being injured or killed by an artificial log structure can be reduced through understanding the specific risks of logs and how to minimize and mitigate them. Not all wood orientations are equally dangerous – in fact orientations range from totally benign to impossible to survive. On medium-sized and larger whitewater rivers in particular, the majority of natural wood orientations and locations are recreationally passable, and relatively low risk. Just as the recreational risk of a wood piece or accumulation exists on a spectrum, so too does the ecological and geomorphological value. This relationship is described in Figure 6.1. Successful channel design projects will select wood orientations and locations that meet primary ecological and geomorphological goals while avoiding the creation of objective hazards.

The following design considerations describe the relative recreational risk associated with specific aspects of wood orientation and location.

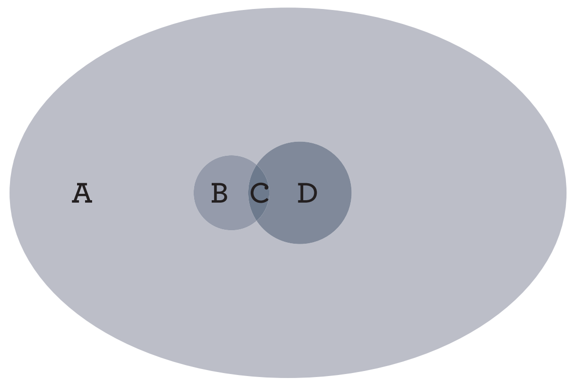
Figure 6.1 | *Diagram showing that a subset of natural wood in a stream has disproportionately high ecological value, that another subset creates objective recreational hazards, and that there is a small amount of overlap. Scale of relationship is estimated.*

A: All wood in stream reach

B: Portion of wood causing high-risk recreational hazards in stream reach

C: Portion of wood that is both ecologically most functional and causes high-risk recreational hazards

D: Portion of ecologically most functional pieces of wood in stream reach



- **Log Height:** Logs of varying heights relative to both the streambed and the water surface pose specific recreational risks and impacts. If a log is high enough above the water (3 feet for kayaks, 6 feet for rafts) it can be safely ducked under (A), and if it is in consistent contact with the streambed (E) it can be safely paddled or swam over. Logs just above the water (B) or at water level (C) require portage. Logs at or below the water's surface but above the substrate (D) can be paddled over but can entrap swimmers. Log structures in contact with the streambed (especially in channel areas with swift current) have relatively small risks of causing entrapment or other recreational hazards compared with logs suspended in the water column
- **Percent Channel Spanned:** Logs not in contact with the streambed that span the entire stream channel are more dangerous than similar partially spanning logs. Partially spanning logs of various heights can often be safely paddled or swam around, especially if they are obvious from upstream and have a clear route past them.
- **Branching:** Branches pose a serious risk of snagging paddlers and swimmers, and trapping them in or under the water. Branches also severely complicate paddling routes over or even around logs. Removing branches from logs placed in streams will minimize these risks and benefit recreationists. Simply removing branches from a sufficient length of a log allows paddlers to avoid portage by opening up safe passage. This practice should allow at least a six foot gap for canoes and kayaks (more in fast or complex current). Be sure to cut branches flush with the tree bole to avoid creating a severe snagging and entrapment hazard for swimmers.

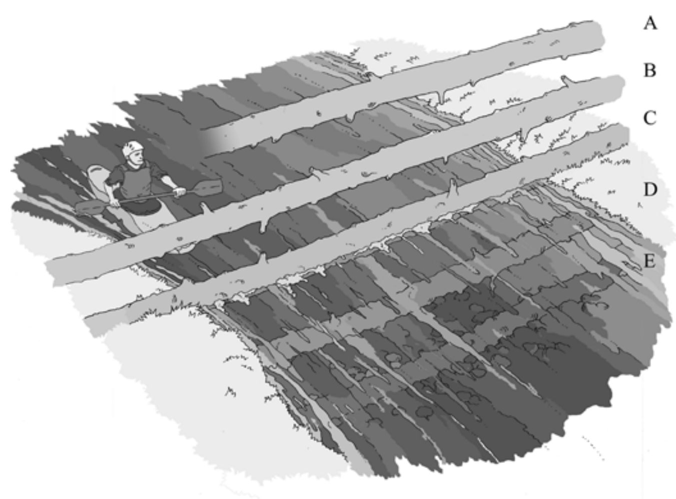


Figure 6.2. | *The height of logs effects whether paddlers or swimmers can duck under (A) or float over (D, E) them – or whether they pose a severe entrapment hazard (B, C, D).*

[1] http://www.americanwhitewater.org/content/Accident/view

- **Number of Logs:** The risks associated with each structure will generally increase with the number of logs. A single log is typically less likely to entrap a paddler than a structure containing two or more logs. Spanning accumulations of multiple logs almost always require portage and can pose significant risks to paddlers and swimmers by creating siphons, sieves, and other entrapment hazards (see Figure 6.3). The only recreational benefit of structures with more logs is that they are more likely to be highly visible and obvious to paddlers, and may slow the approaching current. Just like single logs, relatively low-risk log accumulations are: not fully spanning, not in strong current, highly visible from upstream eddies, easily portaged if necessary.
- **Visibility:** Avoid placing higher-risk log structures on or just downstream of corners or immediately downstream of significant drops to enhance paddlers' ability to see them and react accordingly. Highly visible structures are easier to avoid or safely navigate.

Figure 6.3 | *Log accumulations like this natural one in Idaho typically require portage and can be high risk.*

- **Portage Opportunities:** Placing logs in locations that allow for shore-based portage reduces risks. Portage requires an eddy upstream of, and within clear sight of, the log. One or more eddies immediately upstream of the log is especially valuable for safety and portage. Portage also requires a stream-bank that is not too steep to traverse and ideally an eddy just downstream from which to launch.
- **Location in the Reach:** Placing logs in rapids and other areas of swift current (versus lower gradient or slower reaches/locations) is more likely to create a high risk feature.
- **Anchoring**: The use of cable, rope, rebar, or other artificial anchoring materials is likely to create extreme entrapment hazards if and when the feature/log is moved by the river. If feature stability is a design objective, embedding logs or weighting them with natural materials will more safely promote stability.

Figure 6.4 | Wood Consideration Summary

CONSIDERATION	LOWER RISK	HIGHER RISK
Height	High or Low	In Water Column
% Spanning	Smaller %	Larger %
Branches	Fewer	More
Visibility	Easier to See	Harder to See
# of Logs	Fewer	More
Portage	Easier	More Difficult
Location	Lower Gradient	Steeper
Anchoring	More Natural	More Artificial

Wood is a valuable stream restoration tool, especially in impaired, relatively low-gradient stream reaches with unnaturally low wood volumes. As wood shifts and moves through and within a stream ecosystem, it can form high risk features. However, channel designers have a large suite of options for utilizing wood in orientations and locations that are *relatively* low risk for paddlers and other recreationists. Plunge pools can be created by spanning branchless logs in full contact with the streambed, eddies can be formed by partially spanning logs in contact with the streambed or highly visible log accumulations, and complex overhead cover can be formed by highly visible log jams that are partially spanning (preferred) or even full spanning with a portage option (if needed). In short, incorporating low-risk elements described in this section can partially or fully mitigate unavoidable high-risk aspects of features.

Figure 6.5 | *Example of high-risk wood, Colorado.*

Figure 6.6 | *Example of low-risk wood, Idaho.*

High-Risk Wood Example: The photograph in Figure 6.5 was taken of two trees placed in a river specifically to pose a risk to paddlers. The perpetrators did an excellent job. The logs exemplify hazardous log structures because they 1) are right at the water's surface and close enough to the substrate to entrap paddlers, 2) are fully spanning the channel, 3) have sharp branches above and presumably below the water, 4) are less visible because they are on a bend in the river, 5) have no eddies upstream to facilitate portage, 6) act together to exacerbate risk, and 7) are in swift rapids, exacerbating the risks due to high water velocities. Additionally, they have destroyed the recreational value of the rapid.

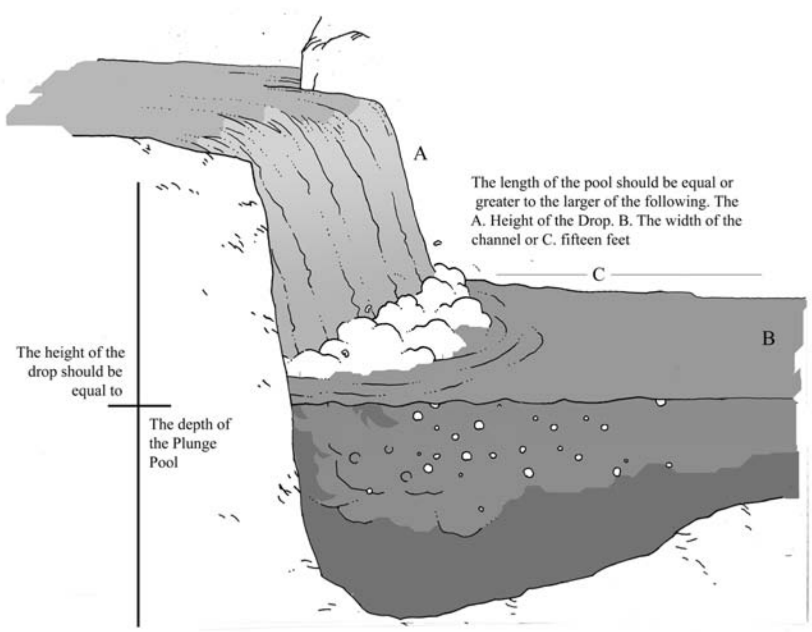
Low Risk Wood Example: Figure 6.6 represents a piece of wood that functions both ecologically and recreationally. Note that the log is 1) in constant contact with the substrate, 2) free of branches, 3) not quite fully spanning, 4) in a relatively low gradient reach, 5) obvious from upstream, and 6) a single log rather than an accumulation of several logs.

7 | Rock Structure Guidelines

The vast majority of natural rapids are formed by bedrock and boulders, and most provide relatively safe and enjoyable recreational passage. The reason for this is that water, in carving and creating a path for itself, also typically creates a viable path for paddlers and swimmers. Similarly, the physics of water often creates deep recovery pools between rapids. Following the patterns and rules of natural rapids can reduce sheer stress, increase stability of the feature, and significantly improve public safety. Below are some basic considerations for constructing features out of rocks.

- **Recovery Pools Between Rapids:** Providing relatively deep pools between rock features allow recreationists to swim to shore if needed. The pool below any drop structure (vertical or sliding) should be free of obstructions, as well as at least as deep as the drop is high, and at least 15 feet long or as long as the height of the drop, whichever is greater (see Figure 7.1). This ensures a paddler can paddle safely over the drop without hitting the bottom, and fish can likely pass in both directions.

Figure 7.1 | *Recovery pools between drops can provide safe passage and resting for paddlers and fish alike.*



- **Eddies in Rapids:** Staging eddies immediately upstream of a rapid are helpful for boat scouting, shore scouting or portaging. Eddies in and immediately below a rapid are helpful for creating a good route, for resting, for setting safety for others, or for accessing the shore in the case of a swim or mishap. Eddies can be create throughout rapids using large boulders or bank protrusions. Eddies immediately adjacent to the base of drops will help avoid the creation of an inescapable hydraulic.
- **Navigable Routes Through Rapids:** Boulders and drop structures placed in such a way that affords a route downstream for paddlers will lower risk. This route can be convoluted, but should exist.
- **Low Risk Drop Lip Shapes (Overhead View):** The shape of a drop, as seen from overhead, is a determining factor of its safety for all recreationists (See Figure 7.2). Dangerous hydraulics can be created by symmetrical drops, such as those with straight lips (top edge that water flows over) either horizontal, diagonal to the flow, or arched with the upstream part of the arch in the center of the drop. Making drop lips irregular but not jagged, and making any arched shapes extend downstream in the center lowers risk.
- **Low Risk Drop Angles (Side View):** Relatively low risk drop structures either have a vertical drop (B) or gently sloping slide (D). Severely overhanging drops (A) and steep sliding drops (C) are relatively high risk because they can have a dangerous recirculation (Letters refer to Figure 7.3). Introducing overhead or cross sectional asymmetry into any design will generally reduce the severity of the hydraulic formed by a feature. Sharp 90 degree lips of drops are typically safer than curved/rounded lips because they create a weaker hydraulic and provide for "boofing" opportunities.
- **Round and/or Smooth Rock:** Sharp rocks can damage boats, injure and entrap swimmers, and erratically accelerate flows. Using round rock will enhance recreational safety.
- **No Underwater Gaps and Overhangs:** Underwater gaps between rocks create a sieve or siphon that can entrap recreationists and equipment underwater. Ensuring that all rocks are buried so that they are either flat or sloping from the substrate towards their center/top (half sphere or gumdrop shape) will reduce the chance of creating a sieve. Placing rocks either touching and filled (so no water goes between them) or at least one meter apart will promote safe passage. Placing undercut (overhanging) rocks in any river or stream will create objective hazards.

Figure 7.2 | *Drop lip shape is a defining feature of drop safety (overhead view)*

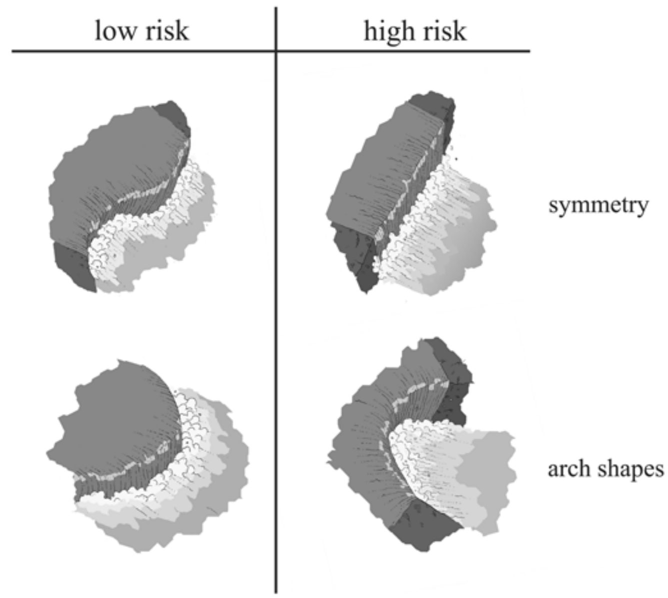
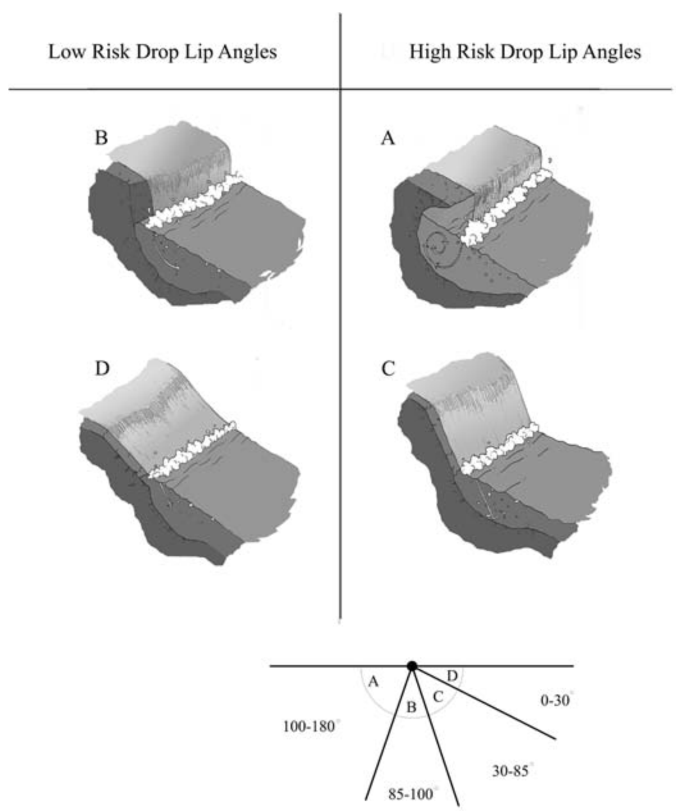


Figure 7.3 | *Drop angle is another defining feature of drop safety (side view)*



8 | General Recreational Considerations

There are a number of general considerations that affect recreational use of rivers, whether moving a single rock or creating an entirely new river channel. Channel designers are encouraged to integrate each of these considerations into all projects.

A. Protecting and Utilizing Natural Structures

All instream channel work should protect natural structure (bedrock, boulders, and native riparian vegetation) in the existing or new streambed area. Many examples exist of projects that needlessly destroyed or modified treasured natural rapids and other river features, rendering them more dangerous and less valuable (See Figure 8.1). Never move or remove natural boulders or bedrock in a natural river without significant consultation with the recreation community.

Figure 8.1 | *In 2011, following flood damage, boulders were removed from Vermont's popular New Haven River and used in road stabilization. The resulting reduction in stream complexity impacts paddlers, fish, and downstream landowners.*

B. Anchoring and Stability

Rivers are inherently dynamic systems and every structure placed in a stream will one day be disassembled and moved by the stream. This process should be a fundamental component of the design. Structures should be viewed as temporary, and be designed to accelerate or guide natural processes which will eventually take over. Generally, using natural materials that are consistent with those already in the watershed will ensure that the rock, wood, and/or other elements of the structure are transported and re-deposited in a natural pattern with natural ecological, geomorphological, and recreational effects.

To lower risks, channel designers should avoid the use of steel cables or rope if at all possible. Cable and rope is among the most dangerous foreign material in any river or stream. Cable and rope pose a severe and often undetectable risk of entrapment when they are in or across moving water. Rebar is also a common stabilization material that can snag and entrap, or severely injure recreationists. Use of rebar is not recommended for this reason, and wooden dowels or stakes may better serve the same purpose. Mortar, grout, or other concrete materials can effectively be used to decrease the flow moving through otherwise porous structures and increase their stability. This material is likely to break down into a natural-like substance and is in many cases a viable stabilization material for rock structures.

Figure 8.2 | *These root wads were installed on the Kenai River in Alaska to prevent erosion. The result is a structure that looks overly symmetrical and obviously man-made, detracting from the natural scenery.*

C. Aesthetics

Many rivers are actively managed for their aesthetic values, whether it be through zoning regulations in suburban and rural areas or through protective management of rivers on federal lands. This management is based on the fact that a large subset of the public derives great pleasure from simply looking at a natural river scene, and paddlers, anglers, swimmers are no exception. Regardless of any special designation, rivers belong to all citizens and should be managed accordingly. Channel design elements that appear artificial can have detrimental aesthetic impacts that can last for a generation or more. As with other aspects of channel design, mimicking natural features can significantly improve the aesthetics of any channel design project. The following are a few channel design components that should be considered.

- Use native materials including rock of similar color, shape, and size as native rock. Use native plant species.
- Arrange logs, rocks, root-wads and other structures in naturally common patterns. As examples, while dozens of root-wads buried in a meander bend may prevent erosion, and many back-to-back symmetrical log plunge pools may offer good adult fish holding habitat, these patterns rarely if ever naturally occur and should be avoided (See Figure 8.2).

- Ensure that all non-native erosion prevention materials biodegrade in a reasonably short timeframe that is commensurate with the anticipated recovery of natural analogs, like riparian shrubs.
- Avoid repeating symmetrical patterns, such as identical meanders, rock veins, or log structures. Seek complexity and diversity in and between structures.

Considering these design components will garner greater public support for projects, reduce the social footprint of projects, and may also have ancillary ecological and geomorphological benefits. Importantly, channel designers have a responsibility to all members of the public to design channels that look, feel, and act naturally.

D. Ecology and Geomorphology

It is beyond the scope of this paper to provide a robust review of ecological and geomorphological considerations of channel design, however some mention of the shared considerations is merited. Native plants and animals evolved in essentially the same naturally complex and dynamic stream environment that paddlers, anglers, and other recreationists have learned to safely enjoy. Generally, channel designs that mimic natural streams will benefit the ecology of the stream – and they will be consistent with natural geomorphology. Of the universe of natural features that designers can choose to mimic, this paper describes and recommends the selection of the significant subset that is relatively low risk for all river recreationists and desirable to paddlers.

It is important to recognize that wood features provide significantly more ecological value in stream reaches with fine substrate (sand – small cobble) than in reaches with large substrate like boulders and bedrock. In low-gradient, fine-substrate reaches wood can be used to add significant habitat complexity for fish and other aquatic organisms. Wood, which is itself a highly mobile type of substrate, most often naturally settles in lower gradient reaches with fine substrate. Boulder and bedrock channels however generally have ample complexity and stability, and are typically higher gradient sediment (and wood) transport zones. Adding wood to high gradient boulder and bedrock streams will pose a greater recreational risk, a likelihood of mobility of the wood, and will offer relatively little habitat value. For these reasons it is recommended that wood structures be favored in low-gradient small-substrate reaches and rock structures be favored in high-gradient large-substrate reaches to meet channel design goals.

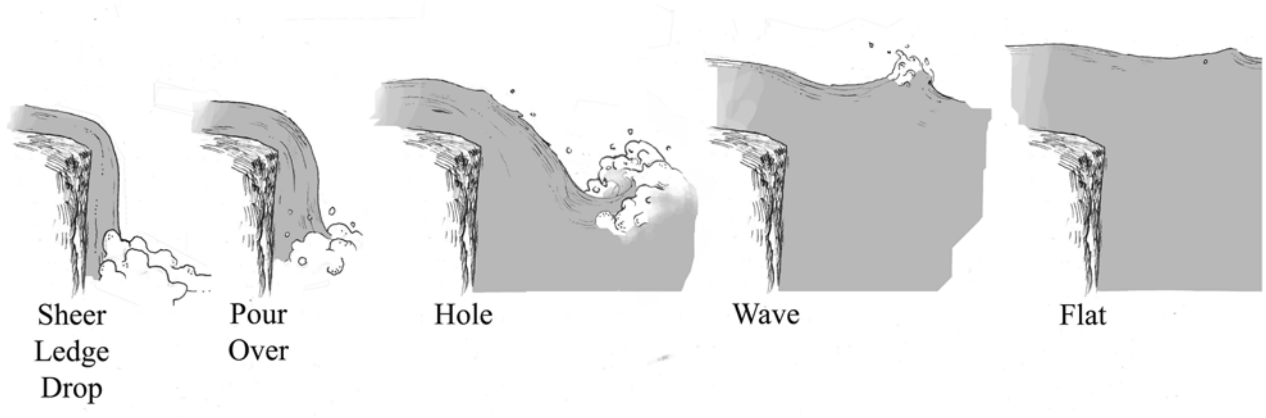
E. Water Levels

Paddling, angling, swimming, and other forms of river recreation are flow dependent. Rivers typically have specific flow ranges that are unacceptable, acceptable, and optimal for these forms of recreation. For paddling, the lowest flows are often too rocky to be navigable, moderate low flows are acceptable, medium flows are optimal, high flows are acceptable, and very highest flows are often unacceptable. Of course what constitutes “low”, “medium,” and “high,” are unique to each river and to a lesser extent to each paddler. Anglers and swimmers typically prefer flows at or near base flow.

Channel designers should ensure that river features do not pose unnecessary or excessive risk at the range of flows preferred by recreationists. For paddling flow preferences, designers should consult with guidebooks and resources like the American Whitewater online Whitewater Rivers Inventory.[2] Generally, channels should be recreationally functional at all flows between the average annual low flow and the average annual peak flow, but this varies widely by reach.

The recreational characteristics of a rock or log will change with water levels in a predictable pattern (See Figure 8.3). Following the rock and log feature design recommendations in this paper will help ensure that features do not create severe hazards within the range of common recreation flows.

Figure 8.3 | *Hydraulic features and their recreational attributes change as flows rise (low flow at left to high flow at right)*



[2] http://www.americanwhitewater.org/content/River/view/

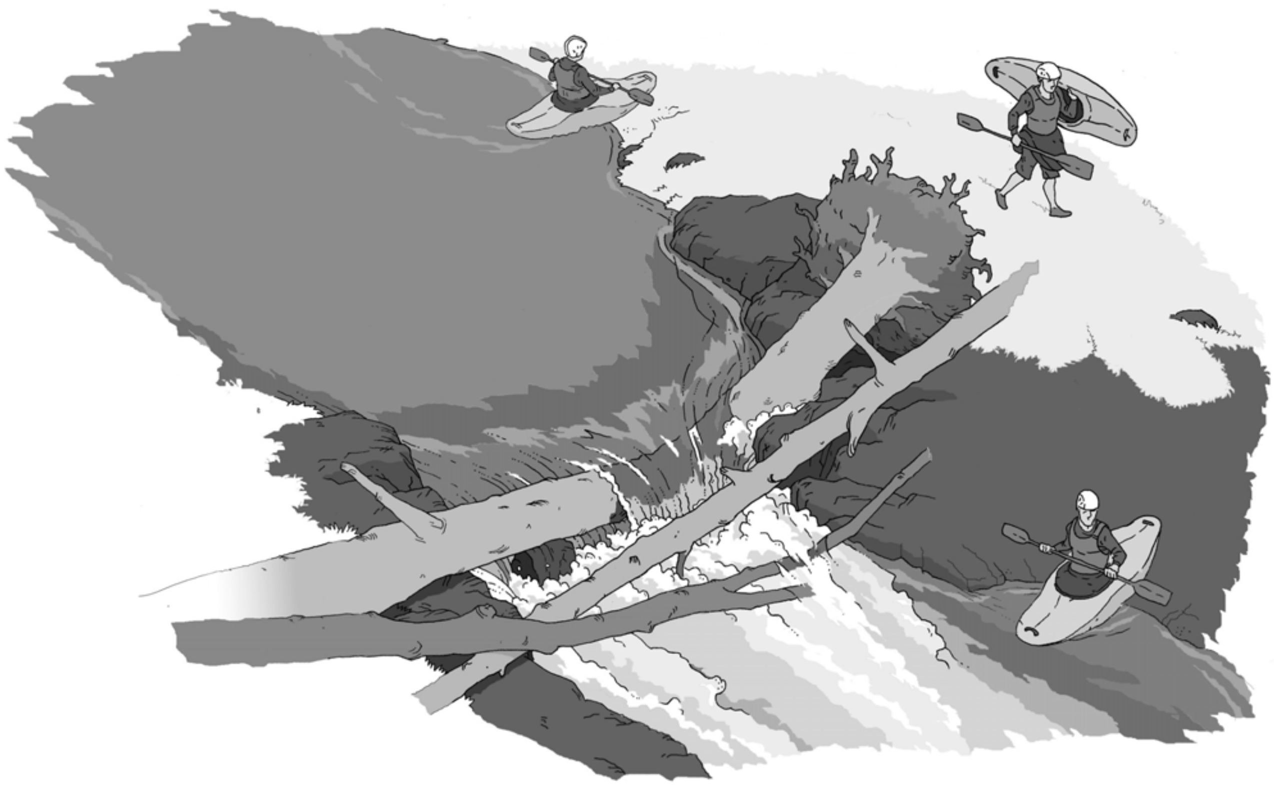
F. Recreational Use Considerations:

It is recommended that channel designers conduct basic research on the historic, adjacent, and most likely recreational uses of the project river reach, and design the reach accordingly. Designs should first and foremost aim to restore similar features to the low-risk features naturally occurring in the reach. As a secondary consideration, designs should seek recreational consistency. For example, if the design reach is in the middle of a popular Class II whitewater river, it would be appropriate to design Class II rather than Class V rapids in the reach. It may be inappropriate to install features that require mandatory portage or pose severe risks on a river popular with paddlers, especially if the river receives significant rafting use (since rafts are difficult to portage). Designers should consult with river managers, guidebooks and online resources like the American Whitewater online Whitewater Rivers Inventory to assess recreational use.

G. Mitigation

There is no geomorphological or ecological need that requires the construction of a feature that is a mandatory portage for paddlers. Paddlers regularly and safely paddle drops of staggering heights and rapids of astounding complexity. With this said, if a designer chooses to create a feature that paddlers may wish to portage, it is important to mitigate the recreational impacts of the feature. To do so, design the feature to 1) be obvious and visible from upstream, 2) have a reasonable take-out eddy upstream and within sight of the feature, 3) have a viable portage route, and 4) have a reasonable eddy to launch from immediately downstream of the feature (See Figure 8.4).

Figure 8.4 | *Unavoidable high risk channel structures can and should be mitigated by providing safe and obvious portage opportunities*



9 | Summary: Putting It All Together:

Natural rivers provide a full suite of ecological habitat, geomorphological processes, and recreational values. Stream channel designers can provide these same values by selecting specific natural feature locations and orientations that: 1) minimize objective hazards, and 2) maximize or at least integrate recreational values.

Figure 9.1 highlights a river channel that is unnecessarily full of objective hazards. Channel designers can meet the same project goals without creating these objective hazards. To avoid creating objective hazards, consider the following rules of thumb.

- Water flowing under rocks or wood is high-risk.
- Water flowing swiftly into anything vertically oriented or porous is high-risk.
- Cable, rope, and rebar are high-risk.
- Sharp rocks are high-risk.
- Drops with obstructions immediately downstream are high-risk.
- Anything geomophologically unnatural is likely high-risk.
- Symmetrical drops can be high-risk, especially if they are steeply sloped or have a rounded lip.

Figure 9.2 highlights a recreationally valuable river channel. To create a recreationally valuable river channel follow these rules of thumb.

- Create no objective hazards.
- Separate rapids and drops with deep pools.
- Create eddies before, within, and after rapids.
- Make all drops asymmetrical and either vertical or less than 30 degree slope, landing in deep pools, with lateral eddies adjacent to their base.
- Design a level of complexity (i.e. whitewater difficulty) that is historically accurate and/or consistent with reference reaches.
- Ensure any potential portages are obvious and possible.

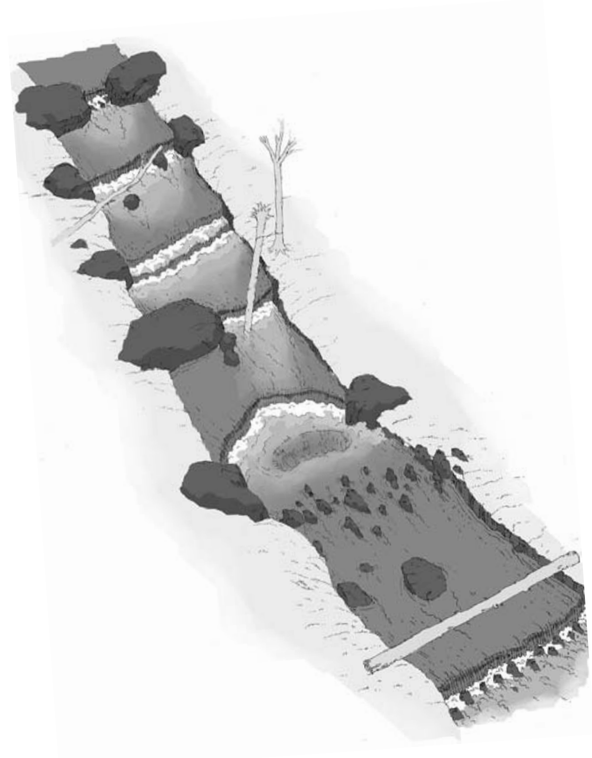


Figure 9.1 | *A poorly designed channel with many objective hazards.*

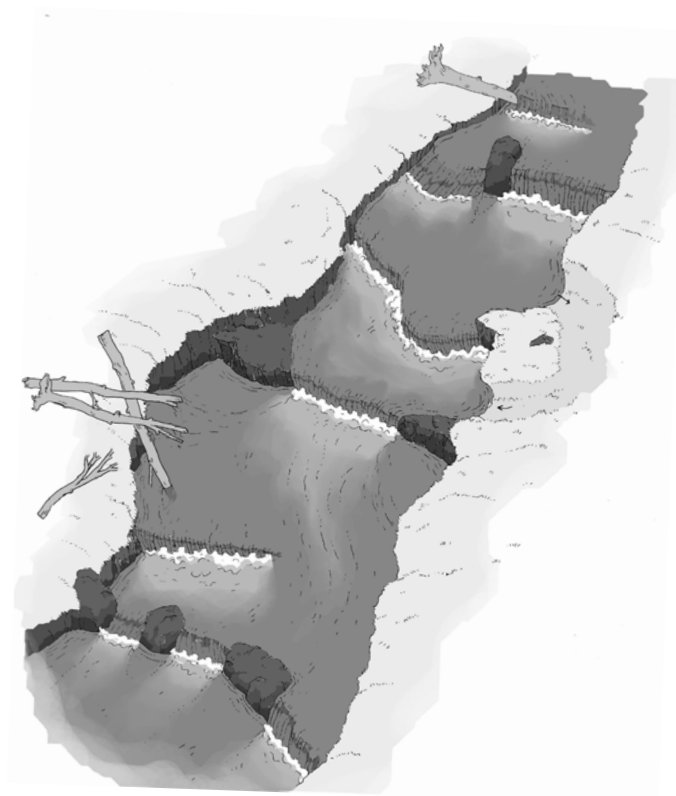


Figure 9.2 | *A well-designed channel with many low-risk and desirable features.*

10 | Conclusions:

Virtually all rivers and streams that you can't jump across at high water are enjoyed by the public through paddling, angling, swimming and/or sightseeing. Integrating recreational considerations into all channel design and modification projects can ensure that these recreational experiences remain high quality and reasonably safe.

About American Whitewater: *Founded in 1954, American Whitewater's mission is to protect and restore our nation's whitewater resources and to enhance opportunities to enjoy them safely. Our members are predominantly conservation-oriented whitewater kayakers, canoeists, and rafters. Our river stewardship program focuses on restoring rivers impacted by hydropower dams, protecting free flowing rivers from environmental harm, and ensuring that river management supports sustainable river recreation. This paper was written to guide the restoration of Washington State's Sullivan Creek, on which American Whitewater negotiated a dam removal.*

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About the Illustrator: *Chad Lewis is an illustrator and avid kayaker based out of central Virginia. He completed his fine arts degree at James Madison University and continued to study illustration at Kent State University. Currently he works as a freelance illustrator and fine artist. Other samples of his work can be seen at: http://www.facebook.com/chadlewisart*

Disclaimer: *This paper has undergone informal peer review from gracious stream modification practitioners, a river safety expert, and river management specialists. It was crafted to share the collective knowledge of the whitewater paddling community regarding river safety with river modification practitioners. It is the author's intention to offer no direct advice to stream modification practitioners on what they should or should not do – but rather to share an opinion on the relative paddling risks and other values associated with various features. This paper is not intended to constitute engineering, construction, geomorphology, hydrology, or any other type of advice, and should not be construed as such. This paper is for informational purposes only. This paper was written as a guide for the restoration of Sullivan Creek, in Northeastern Washington.*

Appendix 1: International Scale of Difficulty

Class I Rapids
Fast moving water with riffles and small waves. Few obstructions, all obvious and easily missed with little training. Risk to swimmers is slight; self-rescue is easy.

Class II Rapids: Novice
Straightforward rapids with wide, clear channels which are evident without scouting. Occasional maneuvering may be required, but rocks and medium-sized waves are easily missed by trained paddlers. Swimmers are seldom injured and group assistance, while helpful, is seldom needed. Rapids that are at the upper end of this difficulty range are designated "Class II+".

Class III: Intermediate
Rapids with moderate, irregular waves which may be difficult to avoid and which can swamp an open canoe. Complex maneuvers in fast current and good boat control in tight passages or around ledges are often required; large waves or strainers may be present but are easily avoided. Strong eddies and powerful current effects can be found, particularly on large-volume rivers. Scouting is advisable for inexperienced parties. Injuries while swimming are rare; self-rescue is usually easy, but group assistance may be required to avoid long swims. Rapids that are at the lower or upper end of this difficulty range are designated "Class III-" or "Class III+" respectively.

Class IV: Advanced
Intense, powerful but predictable rapids requiring precise boat handling in turbulent water. Depending on the character of the river, it may feature large, unavoidable waves and holes or constricted passages demanding fast maneuvers under pressure. A fast, reliable eddy turn may be needed to initiate maneuvers, scout rapids, or rest. Rapids may require "must" moves above dangerous hazards. Scouting may be necessary the first time down. Risk of injury to swimmers is moderate to high, and water conditions may make self-rescue difficult. Group assistance for rescue is often essential, but requires practiced skills. A strong eskimo roll is highly recommended. Rapids that are at the lower or upper end of this difficulty range are designated "Class IV-" or "Class IV+" respectively.

Class V: Expert
Extremely long, obstructed, or very violent rapids which expose a paddler to added risk. Drops may contain large, unavoidable waves and holes or steep, congested chutes with complex, demanding routes. Rapids may continue for long distances between pools, demanding a high level of fitness. What eddies exist may be small, turbulent, or difficult to reach. At the high end of the scale, several of these factors may be combined. Scouting is recommended but may be difficult. Swims are dangerous, and rescue is often difficult even for experts. A very reliable eskimo roll, proper equipment, extensive experience, and practiced rescue skills are essential. Because of the large range of difficulty that exists beyond Class IV, Class 5 is an open-ended, multiple-level scale designated by class 5.0, 5.1, 5.2, etc… each of these levels is an order of magnitude more difficult than the last. Example: increasing difficulty from Class 5.0 to Class 5.1 is a similar order of magnitude as increasing from Class IV to Class 5.0.

Class VI: Extreme and Exploratory Rapids
These runs have almost never been attempted and often exemplify the extremes of difficulty, unpredictability and danger. The consequences of errors are very severe and rescue may be impossible. For teams of experts only, at favorable water levels, after close personal inspection and taking all precautions. After a Class VI rapid has been run many times, its rating may be changed to an appropriate Class 5.x rating.