Section 3:
River Dynamics [1]

Moving water has power. A swiftwater rescuer needs to understand moving water. This section covers river dynamics which provide the foundation for river reading. The dynamics of moving water covered in this section includes river currents, river obstacles, and river hazards.

River Currents

<b> **River Right and River Left** – River right and river left are an orientation used by river users. The orientation is noted on many of the diagrams. Looking downstream, river right is the right shore and river left is the left shore. Looking upstream, river right is the left shore (if looking downstream), and river left is the right shore (if looking downstream). Looking upstream, what is on the right is really on the left, and what is on the left is really on the right.

<b> **Primary Current** (Figure 3.1) – The primary current refers to the general direction in which the river is flowing. It is the current found in an unobstructed main channel. In Figure 3.1, the primary flow is represented by the laminar flow. The slowest moving water is next to the bottom and each successive layer of water toward the surface flows faster than the layer below it. The fastest moving water is found just below the surface. This is because the air next to the surface creates friction which slows the surface water slightly.

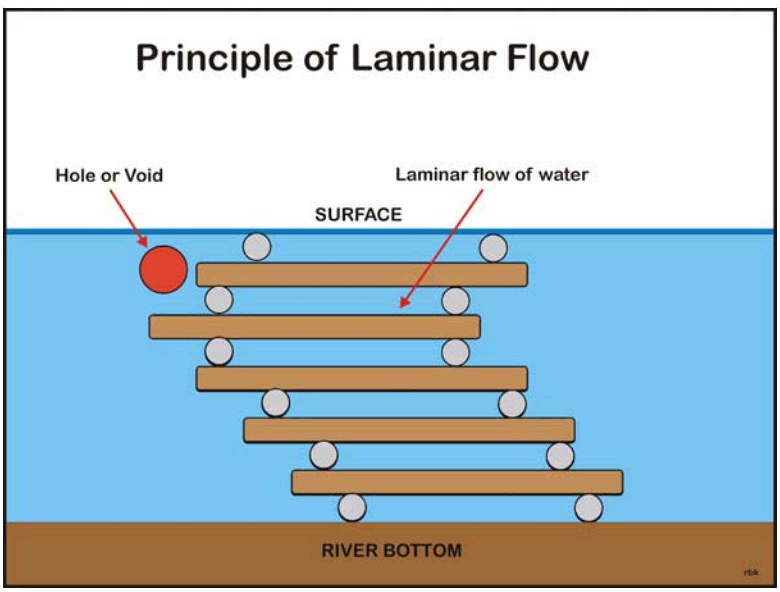

Figure 3.01: Laminar Flow – Laminar flow is like a series of sheets of plywood where each layer travels at the speed of the sheet below it plus its own speed. Source: author – [file:\RIDY-LaminarFlow.cdr]

A way to conceptualize this principle is to imagine sheets of plywood stacked on the floor with wooden dowels between each of the sheets of plywood. Push the stack of plywood. The next higher sheet of plywood on the stack will travel at the speed of the lower sheet plus its own speed. Hence, the higher the stack of plywood, the greater the speed that the plywood. The last sheet of plywood representing the surface of the water travels slightly slower than the sheet below it because of friction with the air above it.

The major implication of this principle for a rescue swimmer is when swimming in the defensive swimming mode. Often, it is difficult to keep the

[1] This section was written by Robert B. Kauffman who is solely responsible for its content. The source material for this section was adapted from a draft of Building Your Canoe Basics (Chapter 6) in *Outdoor Adventures: Canoeing*. American Canoe Association (eds), Human Kinetics, March , 2008. This section is copyrighted © Robert B. Kauffman, 2016.

feet on the surface of the water since the slower current below the surface tends to pull the feet downward.

The laminar flow is a function of the depth of the river. Since the channel is normally deeper in the middle and decreases in depth to the shore, the current in the center or deepest part of the channel is faster than current close to the shore. The difference in the speed of the current on the surface of an unobstructed channel is represented in Figure 3.2. Again, this represents a normal river channel which gets shallower toward the shore. As a footnote, canals, bridge abutments, and similar walled channels are similar to taking the center out of the channel all the way to the canal wall, bridge abutment, or similar walled channel. In these situations, there is little current differentiation from the center of the river to the channel wall. Rocks and other obstructions can affect this flow. Submerged rocks in deep channels can force vertical currents that reach the surface as boils.

<b> **<u>Downstream and Upstream "Vs"</u>** (Figure 3.3 and Figure 3.4) – Two rocks or other objects can create a restriction in the water where the water flows between the rocks to form a small chute. The rocks form an upstream V and the chute between the rocks forms a downstream V. There is a difference in vertical height between the upstream and downstream Vs. The water piles up against the rock creating an increase in the vertical height of the water. Also, it creates a cushion of water against the rock. Conversely, the water drops off quickly in between the two rocks forming a chute and a downstream V. Also, it is lower in elevation. Boaters and swimmers look for this difference in height as they look for downstream Vs and avoid upstream Vs. Figure 3.3 shows a typical stretch of river with its upstream and downstream Vs. Figure 3.4 provides a view from a swimmer's perspective of the

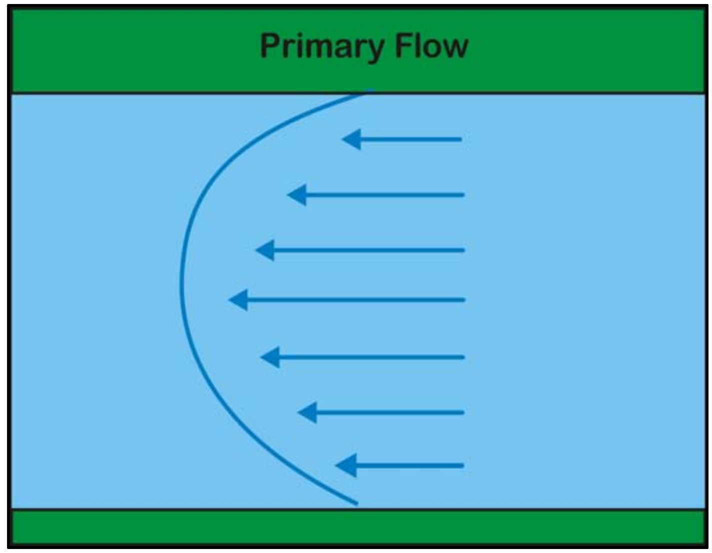

Figure 3.2: Primary Flow – The shores are shallow and the center of the river is deeper. This normal contour results in faster current in the center of the river and slower currents toward the shore. Source: author – [file:\RIDY-PrimaryFlow.cdr]

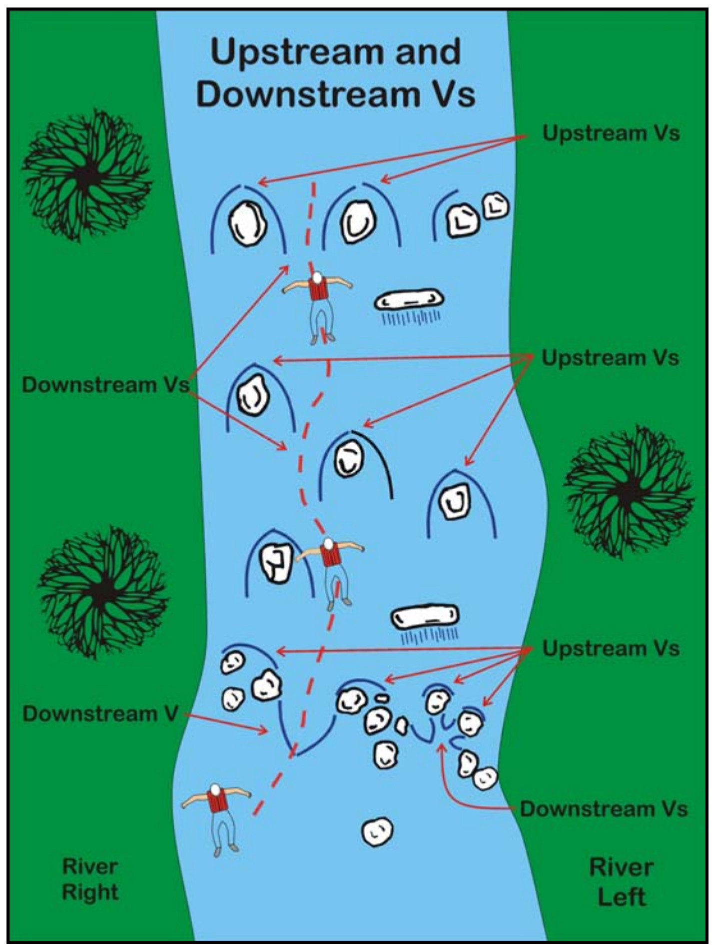

Figure 3.3: Upstream and Downstream Vs – This scene is a typical stretch of river where the swimmer looks for the downstream Vs and to avoid the upstream Vs. Source: author – [file:\RIDY-Vs.cdr]

change in elevation and the upstream and downstream Vs. The height differential may be slightly exaggerated for emphasis. This is the view the swimmer would have running the stretch of river in Figure 3.3.

<b> **<u>Bends</u>** (Figure 3.5) – Rivers tend to meander. When the river bends, inertia forces the main current toward the outside of the bend. As the deeper, faster and the more powerful current reaches the outside of the bend, it turns downward and creates a spiraling effect off the bottom of the river that leaves more room for surface water on the outside of the bend. The force of the water tends to erode the outside of the bend where trees and other debris fall into the river where they can form strainers. In contrast, the slower, shallower and less powerful current is usually found on the inside of the bend.

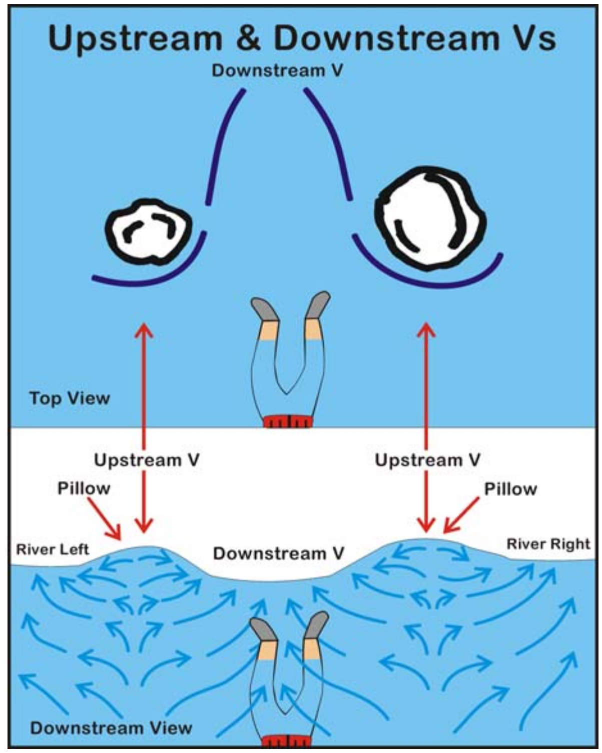

Figure 3.4: Upstream and Downstream Vs – This is the view from the swimmer's perspective. Note the subtlety in height between the upstream Vs (high) and downstream Vs (low). Source: author – [file:\RIDY-Vs&Tongues.cdr]

When swimming around a bend, the swimmer normally hugs the inside of the bend where the current is slower. Moving to the outside of the bend, the swimmer encounters the faster water which tends to push the swimmer into the outside bank where the swimmer is likely to encounter a strainer or other obstruction. Second, when swimming a bend, the swimmer sets a slight ferry angle with the head pointing toward the inside of the bend. Since the current is going faster on the outside of the bend, if the swimmer remains parallel with the current, she will be turned around by the current. This is because the head and shoulders are moving faster than the feet.

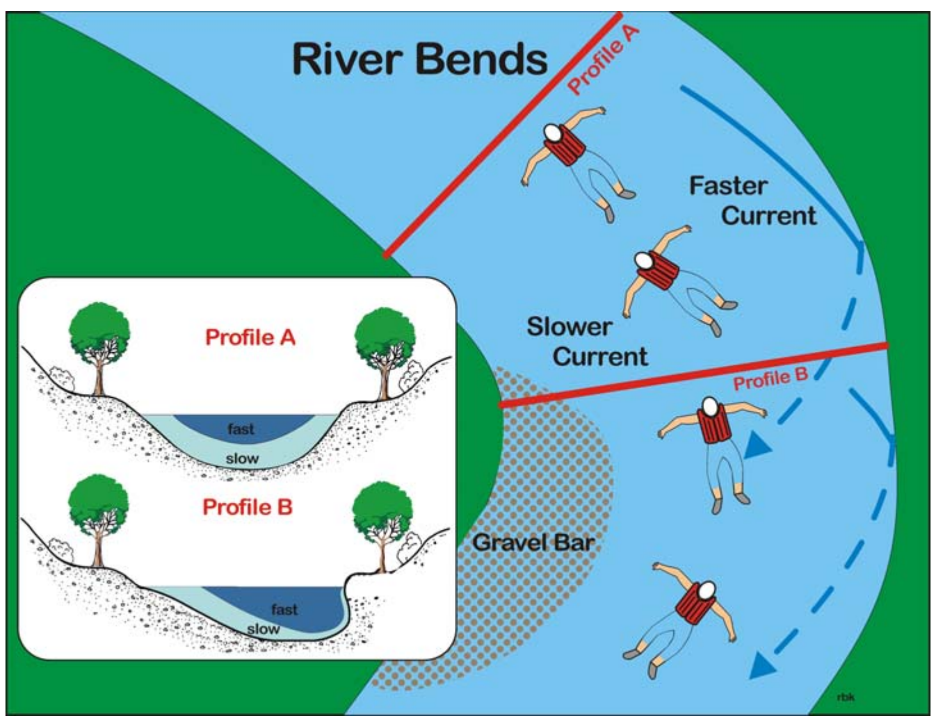

Figure 3.

<b> **<u>Chutes and Waves</u>** (Figure 3.6) – A narrow constriction in the water forces the water to increase its speed through the constriction. This water usually forms a smooth tongue of water. After the

water passes through the constriction, its deceleration into a deeper and slower water results in a series of uniformly spaced scalloped shaped standing waves. The constriction can vary several feet in width to a river wide constriction. The former creates a simple drop with small waves. The latter river wide constriction can create large standing waves several feet in height from the trough to top of the wave. An important consideration for the swimmer is to coordinate her breathing so that she breaths in between the waves and not as she goes through the wave.

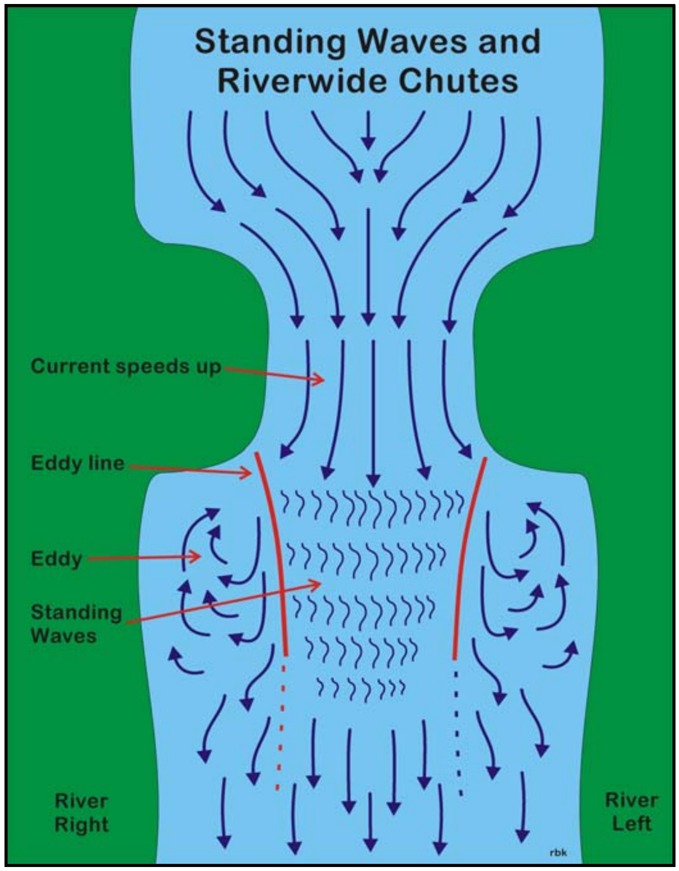

Figure 3.6: Chutes and Waves – Water speeds up in a constriction of the channel and then it is dissipated as it drops. This creates a series of standing waves. Source: author – [file:\RIDY-Chutes.cdr]

River Features

Rocks are the main obstacles found in a river. The depth of the rock in the water and its size are key factors in determining the effect of the rock on river dynamics. Pillows, holes and eddies are closely related. A totally submerged rock may have little or no effect on the surface current. As the rock gets closer to the surface, it will force the water passing over it upward to the surface creating a small wave or *pillow* downstream of the rock. As the rock or obstruction widens, water from the side cannot fill in behind the rock. This results in a depression or void behind the rock. Now the water flowing over the rock attempts to fill the void creating a *hole* or *hydraulic* behind the rock. As the rock becomes exposed, the water can no longer flow over the rock and can only fill the void behind the rock from the sides. *Eddies* are created by the water filling in the void from the sides behind an exposed rock.

<b> **<u>Eddies</u>** (Figure 3.7) – Eddies are formed behind rocks or other obstructions in the river. Water flows past the obstruction creating a void behind the object which the water attempts to fill. There are three distinct parts of an eddy which are created by the water attempting to fill the void.

The first part of the eddy is where the water in the main current rushes by the rock so fast that in order to fill the void the water has to flow back upstream (see #1 in Figure 3.7). This creates a very strong current differential between the main current and the current in the eddy. The interface between the downstream current and the upstream current creates an eddy line or even an eddy wall. As the current increases dramatically, the eddy line becomes an eddy wall. An eddy wall is the vertical height difference between the downstream current and the current in the eddy attempting to fill the void behind the rock. If there is an eddy wall, there is a noticeable downhill current inside the eddy also. For a rescue swimmer, this powerful of an eddy can be problematic and the rescue swimmer can find the eddy unfriendly. However, most eddies will have an eddy line where there is little or no vertical difference between the main current and the upstream current in the eddy.

The third part of an eddy is where the water in the main current enters the void behind the rock so far downstream that it continues on downstream but at a slower rate then the main current (see #3 in Figure 3.7). This area of an eddy can be problematic for rescue swimmers because rescue swimmers may think that they are in the upstream current in the eddy when they are really moving downstream, and quickly falling out of the eddy (see Figure 3.7). In addition, since the current is moving downstream in the eddy, there is no real eddy line present in this portion of the eddy. Many beginning rescue swimmers will prefer entering an eddy in this area because there is no current differential and there is less risk of having to cross the eddy line. This is okay but remember to swim upstream into the eddy.

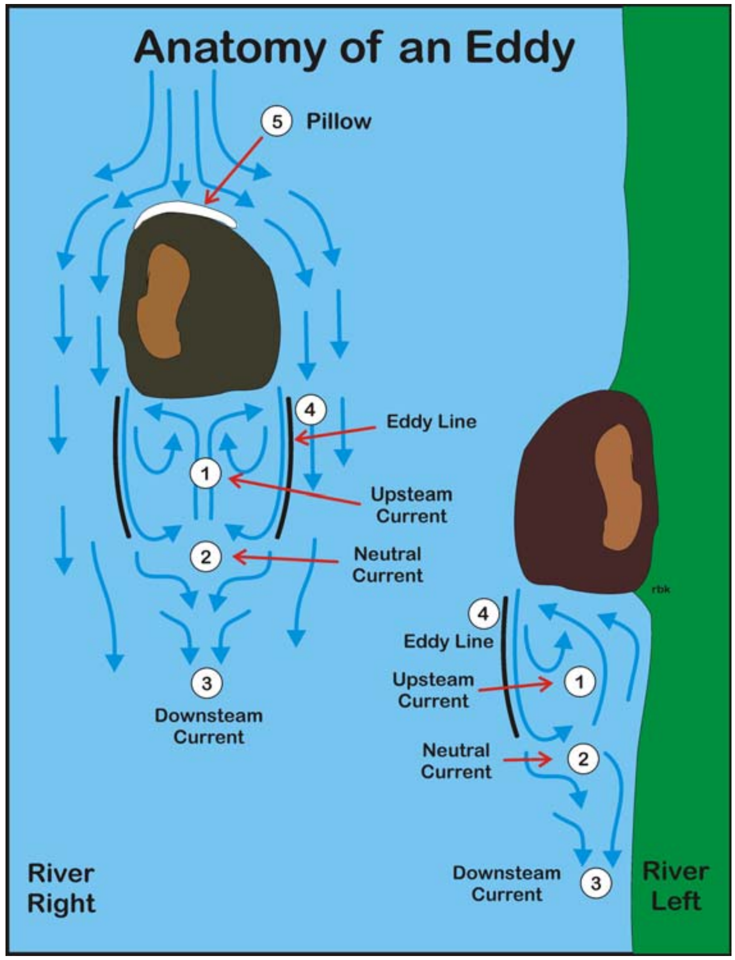

Figure 3.7: Anatomy of an Eddy – In the anatomy of an eddy, there are three parts. There is the water moving back upstream. The eddy line occurs in this section. There is a neutral area, and there is a downstream moving area. Source: author – [file:\RIDY-EddyAnatomy.cdr]

The second part of the eddy is the interface between the current moving upstream and downstream in the eddy. The current here is neutral. In a strong eddy, this is often the ideal location for a rescue swimmer to remain stationary. They aren't being plastered against the backside of the rock by the upstream current where it is difficult to exit the eddy, and they aren't falling downstream either.

Conceptually, the three parts of an eddy have many of the same characteristics as a hole or hydraulic. Both are caused by the river attempting to fill a void. In a sense, an eddy is a hole rotated on its side. Most eddies are friendly and rescue swimmers will use them extensively as they eddy hop down a river. However, remember that some eddies can be violent and very unfriendly also.

<b> **<u>Hydraulics and Holes</u>** (Figure 3.8) – A hole occurs in the river when a rock or other obstruction of sufficient width to prevent the water from filling in the obstruction from the side forces the water flowing over the rock to fill the void or depression behind the rock. As the water flows over the rock, it plunges down to the bottom of the river and races downstream. As it races downstream, the water shoots back up to the surface where it moves in one of three directions. A portion of the water re-circulates back upstream to fill the void behind the rock (1). Further downstream, some of the water comes up to the surface and continues on downstream (3). This water travels at a slower rate than the general flow of the river and quickly picks up speed as it moves downriver. In between or at the interface of the upstream and downstream flow, the flow is neutral in that it is not really flowing downstream or upstream (2). This neutral area is called the "boil."

The shape of the hole affects how friendly it is. In a *smiling hole* the center of the hole is further upstream than the sides. This creates the impression that the hole is smiling when looking at the hole from the upstream side. It tends to be more friendly to a swimmer or paddler since they will find it easier to maneuver to the side of the hole where they can exit the hole.

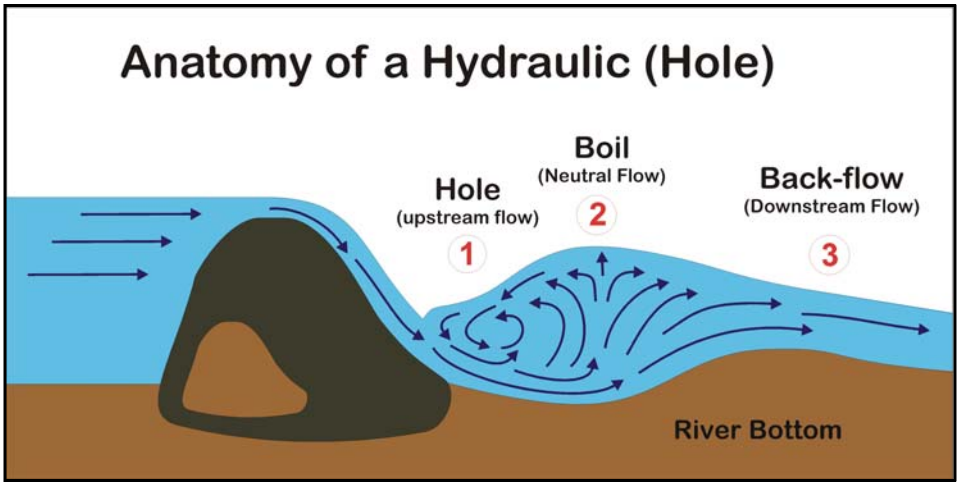

Figure 3.8: Anatomy of a Hydraulic – In the anatomy of an eddy, there are three parts. There is the water moving back upstream attempting to fill the hole. There is the neutral area or boil, and the downstream flow. Source: author – [file:\RIDY-HydraulicTypical.cdr]

In contrast, in a *frowning hole,* the middle of the hole is downstream of the sides. From the upstream side of the hole, it looks like it is frowning. Since the middle of the hole is downstream, the force of the hole tends to move the swimmer or paddler to the center of the hole where it is strongest and most powerful. These holes are often called *keepers* because they keep a person stuck in the hole. They are difficult to exit because the swimmer or paddler has to literally paddle uphill to reach the side of the hole where they can extricate themselves from the hole.

If you are paddling a canoe or kayak you can easily feel where you are in the hole. If you are on the upstream side of the boil, you can feel the pull of the current pulling the canoe upstream and into the hole. Conversely, if you are on the downstream side of the boil, you can feel the boat slipping downstream and dropping out of the hole. If you are sitting on the shore and watching the paddler you can play a little mental game where you look closely at the attitude of the canoe and tell where the canoe is in the hole. Look at the trim of the boat. If the stern is lower than the bow, then the canoe is in the downstream portion. Unless they paddle hard, they are out of the hole, and they might as well ferry to the shore and try again. If the bow is lower than the stern, the canoe will move upstream and into the hole.

Understanding these currents on an experiential level can be of benefit to the swiftwater rescuer. The rescuer can approach the victim in the downstream current behind a low head dam or keeper hole and throw a rope to the victim trapped in the hole. This area is perfectly safe for the rescuer, but the rescuer needs to know exactly where they are in terms of these three currents. Once the rescuer crosses the boil, it is all downhill and they too can become a victim. This is not an uncommon situation. This author has reviewed more than one case where the rescuer crossed the boil and died. It is important to know where you are in terms of the currents pictured in Figure 3.8.

<b> **Pillows** (Figure 3.9 and Figure 3.10) – As the rock approaches the surface, it will force the water passing over it upward to the surface creating a small rounded wave or pillow downstream of the rock. The further underneath the water that the rock is in the water, the further downstream the pillow. And, as the rock moves closer to the surface, the pillow moves closer to the rock until it is directly over it. It takes experience for a swiftwater rescuer to recognize which pillows are close to the surface and need to be avoided and which ones are deep enough not to pose a problem.

When the rock finally emerges out of the water, the pillow becomes a cushion of water that flows up against the rock forming a *cushion*. A boater floating up on a well developed cushion can use the cushion to avoid broach on the rock. Regardless, it requires quick thinking and a quick reaction to avoid broaching. In addition, if the current is powerful enough, the rock may actually form a series of compression waves upstream of the obstacle (Figure 3.10).

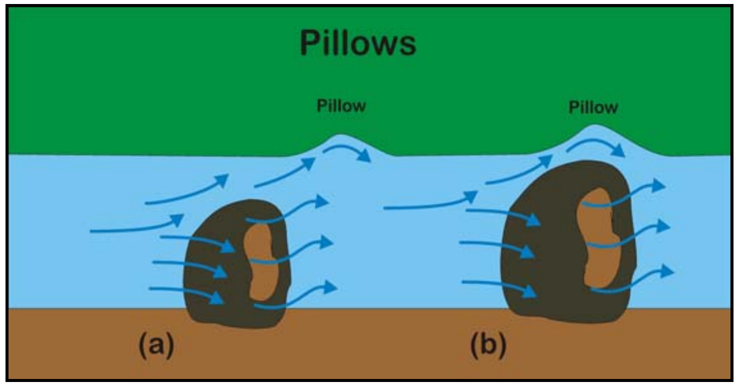

Figure 3.9: Pillows – The water hits the top of the rock forcing it to the surface creating a downstream bubble or pillow on the surface. Source: author – [file:\RIDY-Pillows.cdr]

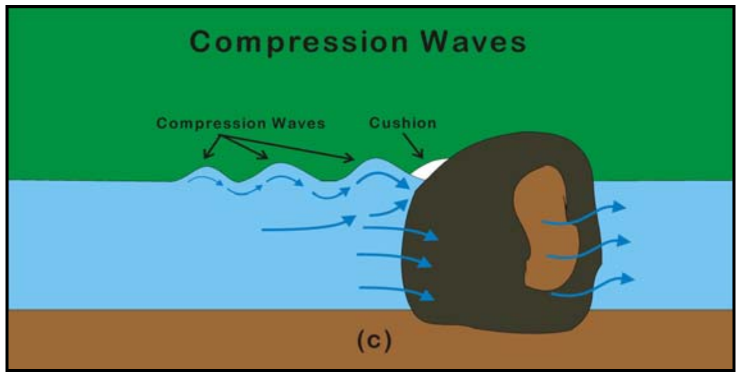

Figure 3.10: Compression Waves – The water hits the front of an exposed rock and creates a cushion because it has no where to go. Source: author – [file:\RIDY-CompressionWaves.cdr]

River Hazards

<b> **Strainers** (Figure 3.11) – Strainers are formed when water flows through an obstacle. Much like spaghetti in a colander, water flows through the strainer leaving the victim trapped helplessly. Stainers are most commonly formed by trees and rocks. STRAINERS ARE KILLERS. They are extremely dangerous and river users should always avoid them.

Trees are the most commonly encountered form of strainers found on a river. As a river continues to carve out a bend in the river, trees along the bend will fall into the river channel as the river current undermines the foundation underneath the tree. Also, a strainer on the bend of a river is particularly dangerous since the current is faster there and the rescue swimmer who is flowing with the current is more likely to be swept into the strainer.

Rocks can also cause strainers. Usually, the rocks are positioned on the bottom in such a way that water will flow thru them to create a strainer. Often, these strainers are referred to as undercut rocks. Water boiling up from the bottom in an eddy or an eddy without an eddy line is often a good indication of an undercut rock.

The strainer drill helps to prepare students for handling strainers. Again, avoidance is the primary strategy. If there is no avoiding the strainer, swim aggressively toward it and try to get as high up onto it to avoid drowning.

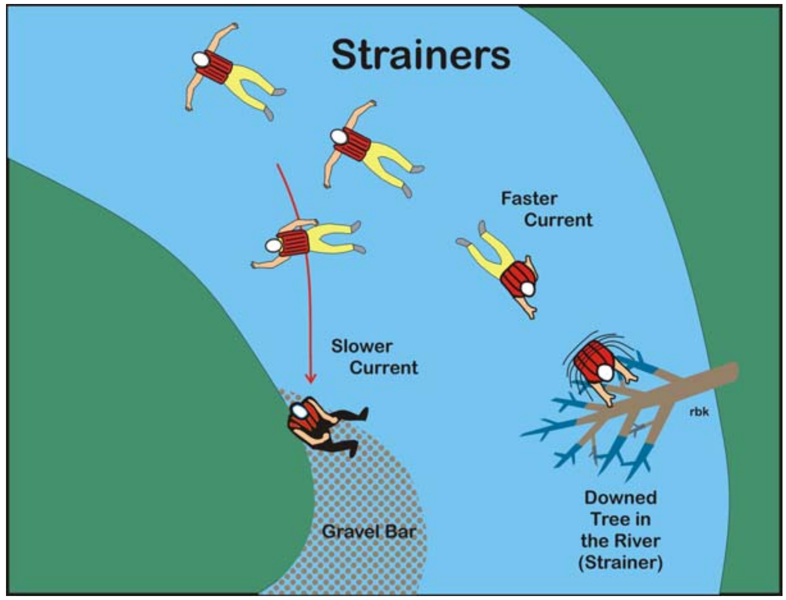

Figure 3.11: Strainers – A strainer allows the water to pass through but holds the swimmer. They are killers and should be avoided. Source: author – [file:\RIDY-Strainers.cdr]

<b> **<u>Undercut rocks</u>** – Most undercut rocks are a form of strainers. The main attribute of an undercut rock is that the water flows underneath rather than around the rock. Depending on its size, the current can sweep a victim underneath the rock and impale the victim in the orifice of the undercut rock (strainer).

For most boaters, a good indication of an undercut rock is that normal river features like an eddy don't behave as they normally do. They seem weird or different and they act weird because the currents are different. The eddy pictured in Figure 3.12 is modeled after and uncut rock on the Lower Youghiogheny River.

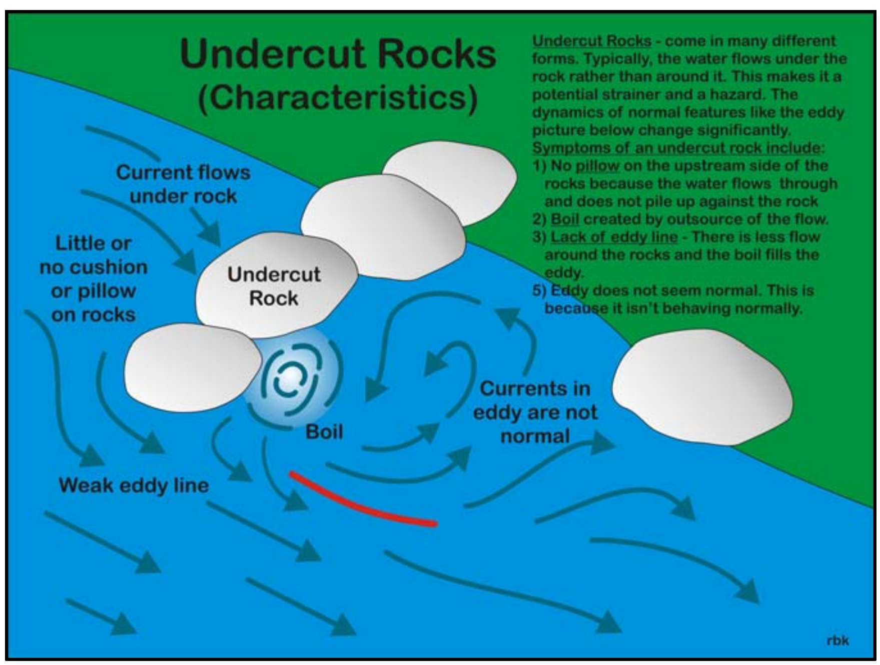

Figure 3.12: Anatomy of on Undercut Rock – To the trained eye, the undercut rock seems very different than a normal river feature. Source: author – [file: \RIDY-UndercutRocks.cdr]

Typically, there are several symptoms or characteristics to help spot an undercut rock. First, the pillow or cushion on the upstream side of the rock is missing. This is because the current is flowing through and not piling up against the rock. Second, the current flowing through the orifice creates a boil with its outflow. The boil and outflow significantly changes the river feature. The eddy pictured does not behave as an eddy normally behaves (see Figure 3.7). Next, there is less current flowing around the rock. The eddy line may be weak or missing. The outflow current may reduce the current differential and eddy line. A boater entering this eddy would immediately experience the lack of an eddy line to cross and the force of the outflow current. Last, because of the outflow and boil, the current in the eddy is different than normal.

<b> **Low-head Dams** (Figure 3.13) – A low-head dam and a hydraulic are essentially the same with some important differences (see Figure 3.8). Examination of Figure 3.8 and Figure 3.13 suggests that they are essentially the same diagrams. However, there are some important differences. The hydraulic behind a low-head dam is a "perfect" hydraulic. It goes from one river abutment to the other. The only exit may be to dive down and catch the water moving downstream. In contrast, naturally formed hydraulics are imperfectly formed and can usually be escaped. A low-head dam is designed to disperse the kinetic energy of the falling water upward rendering it harmless. Unfortunately, hydraulic is perfectly formed and extends from one abutment to the other abutment. This is why they are called the drowning machine.

A *horizon line* is the usual indicator of a river wide obstacle like a waterfall or low-head dam. Actually, this is a variation of the differential heights created by upstream and downstream Vs (see Figure 3.3), except there is no height differential. Hence, the horizon line. As you look downstream, there will often be a section of calm or smooth-looking water followed by a line across the river where the water drops out of sight. Trees on your side of the horizon line will look normal. However, the trees just downstream from the horizon line often look as if someone cut a section out of their trunks. If the horizon line is formed by a low-head dam there are usually abutments on each side of the dam which are a clear indication of the dam.

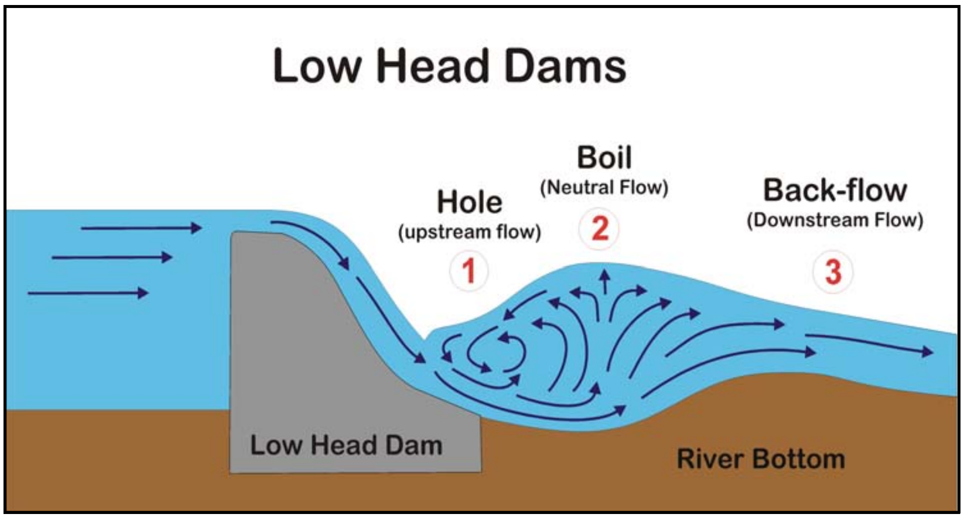

Figure 3.12: Low Head Dams – Low head dams are perfect hydraulics from abutment to abutment. They are killers and should be avoided. Source: author – [file:\RIDY-HydraulicLowHeadDam.cdr]

There are several approaches to rescuing a victim caught in the hydraulic of a low head dam. Several of these are in the province of the rescue squad and their specialized equipment. The first rule for any rescue attempt is to understand that the hydraulic behind a low head dam is a drowning machine. This applies to rescuers also. An untethered rescuer trapped in the hydraulic becomes another victim. There are cases where a bystander with full knowledge of the dangers of low head dams attempted a rescue and drowned in his rescue attempt to rescue two victims. One victim recycled out of the hydraulic and survived. The other victim along with the rescuer drowned.

The following are some rescue methods. The first requires the specialized equipment of a rescue squad. A fire hose is capped with a special cap and inflated with air. The hose is extended to victim trapped in the hydraulic. It works but requires the specialized caps. A Tefler lower can be used. This requires considerable setup time. Third, a power boat can maneuver in the slowly moving downstream current behind the hydraulic and throw a throw bag to the victim. A grappling hook can be used in place of the throwbag. A tethered victim can enter the hydraulic and effect a rescue. However, this can endanger the rescuer and should be used as a last resort, if at all. Maneuvering in the slackwater behind a hydraulic by rescuers requires an empirical understanding of the parts of hydraulic. This point cannot be emphasized enough.

<b> **Old Man-made Structures** (no figure) – Most rivers contain man-made structures such as old dams or bridge abutments that have fallen in disuse. Sometimes these structures are potentially a fun place to play with a canoe or kayak. Always use caution around these structures. Rip-rap may contain large spikes. Old dams and bridge abutments may contain reinforcing rods or sharp rocks that can create nasty injuries. Check the site at low water for hazards and if there is any doubt, find another place to play.

<b> **Drowning Trap Flows** (Figure 3.14, Figure 3.15, and Figure 3.16) – Any water level on the river can be hazardous. Ask people when the river is dangerous. Most people associate flood-like conditions with danger like muddy water, water flowing over the banks, water in the trees, floating debris and big waves. Floods and high water are dangerous and most people recognize the danger and stay off the river (Figure 3.14).

On many rivers, recreational fatalities tend to occur at moderate water levels when the river is well within its banks and the river looks perfectly normal (i.e. It is not flooding). The normal cycle of flows for rivers is that during the summer when most people visit the river, the water level drops to where the moving water is no longer a contributing factor in the fatalities. However, if the water level rises, the river can become very dangerous (Figure 3.15).

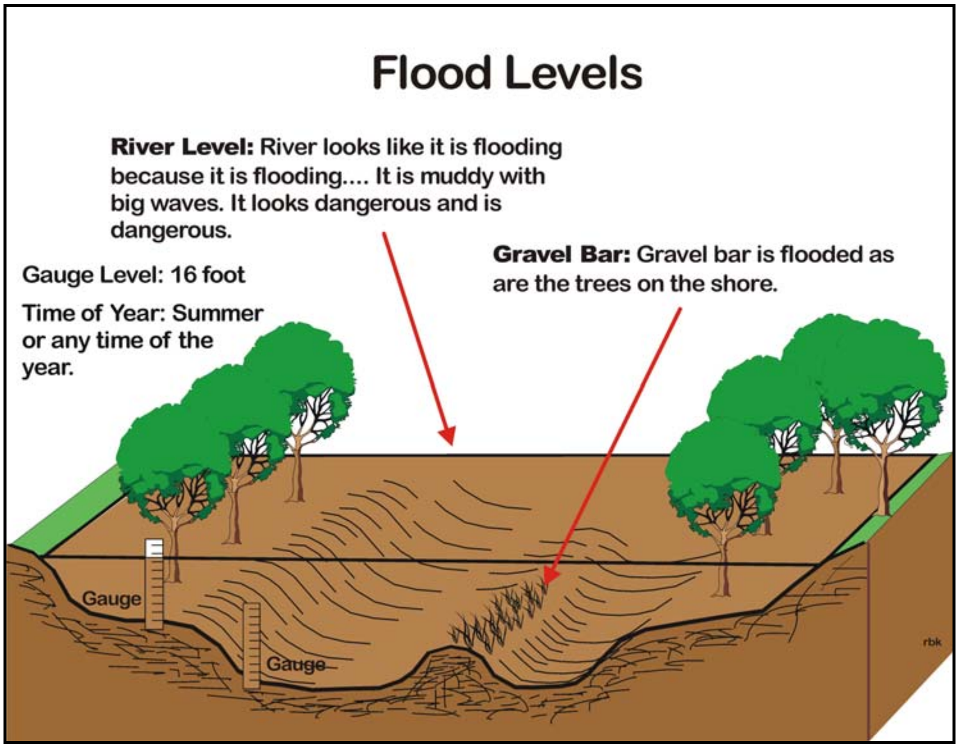

Figure 3.14: Flood Levels – Intuitively, most people recognize rivers flooding and the dangers associated with them. They avoid flooding rivers. Source: author – [file:\RIDY-DrowningTrapFlood.cdr]

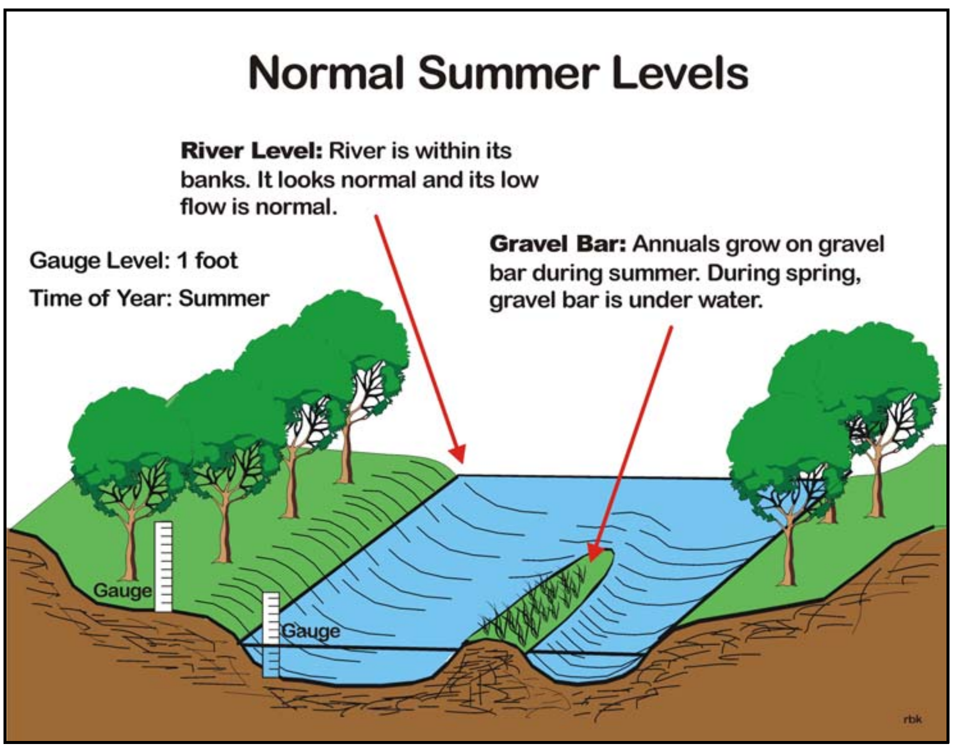

Figure 3.15: Normal Summer Flows – In the summer when most people visit rivers, the river is at low flow where it tends to lose its power as a contributing factor in accidents. Source: author – [file:\RIDY-DrowningTrapNormal.cdr]

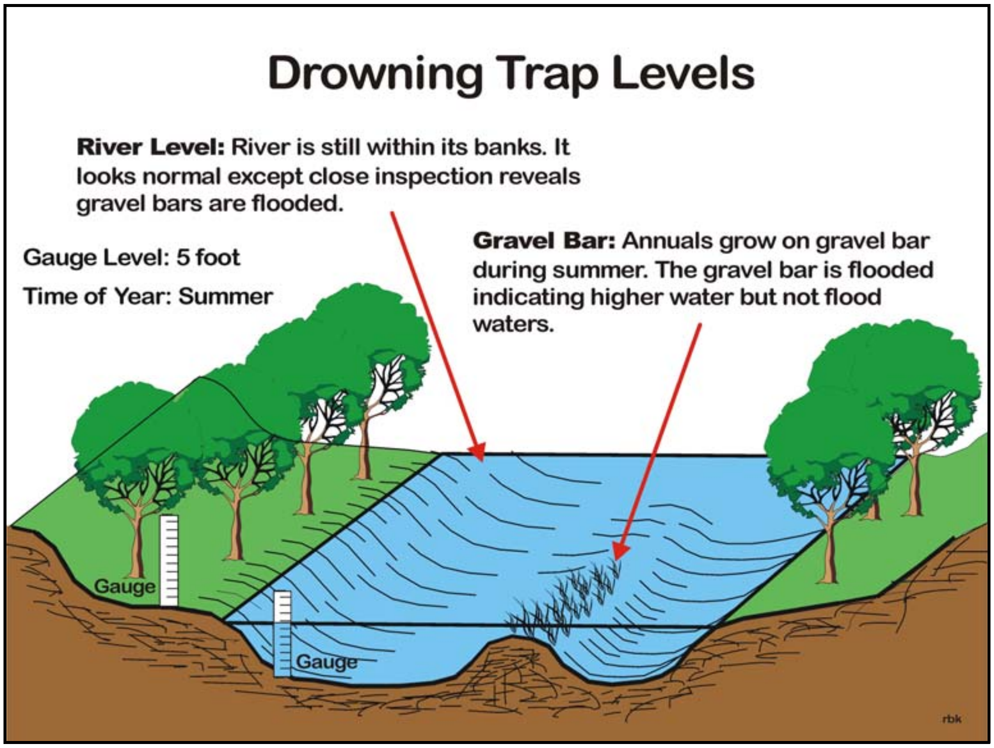

Figure 3.16: Drowning Trap Flows – When high flows occur during summer, the river current has the power to become a contributing factor in drownings. Since the river is within its banks, people don't perceive it being dangerous because there aren't flood conditions. Source: author – [file:\RIDY-DrowningTrapNormal.cdr]

Depth, velocity and deceptiveness define the drowning trap (Figure 3.16). At these moderate flows the river has the power (depth and velocity) to drown, yet it is deceptive since people tend to associate flood conditions with danger rather than moderate flows. The cross-sectional profile of a typical eastern river illustrates the relationship between moderate drowning trap flows, summer low flows and flood levels which people normally perceive as being dangerous.

The depth of the water is a key determinant of its velocity and its power. Imagine standing in moving water about waist deep. With some deliberate care you can brace yourself against the current and stand in the water. Add another foot of water so that the water is above your waist. Now the river current can easily move you. Perhaps it may knock you off your feet and sweep you downstream. When the river's speed reaches that of person walking fast, it begins to have the power to move you, knock you over and depending on circumstances, drown you.

A good indicator of drowning trap levels is when annual vegetation on gravel bars are inundated during the summer months. Look for those areas which were under water during the spring runoff. When this vegetation becomes either partially of fully under water, the river is higher than normal and may be in the drowning trap flows.

The third component of the drowning trap is deceptiveness. When asked, most people correctly associate flood-like conditions as being dangerous. And they are dangerous. However, in the Drowning Trap flows the river is well within its banks and to the casual visitor, the river looks perfectly normal. A study on the

Potomac River in Maryland found that three fourths of the river visitors visited two or less times to the river. Hence, most visitors have no reference point to determine what is the normal summer flow of the river. The river is not flooding and it looks normal because it is well within its banks. However, it has the depth and velocity to contribute to an accident. In this way it is deceptive because people don't readily recognize the danger for what it really is.

Summary

Having an understanding of river dynamics is important for the rescue swimmers. First, it helps the rescue swimmer not to become a second victim. This was evident in rescues behind a low head dam. Second, understanding and having familiarity with river dynamics is important as the rescuer moves in the river. It helps to facilitate a rescue, and again, it helps the rescuer in not becoming a second victim during the rescue. Third, understanding river dynamics goes hand-in-hand with river rescue. Last, wading and swimming rapids helps the rescuer to become familiar with the medium with which they are working. This familiarity is always a good thing.

References

Bennett, J., (1996). *The Complete Whitewater Rafter*. Camden, Maine: Ragged Mountain Press.

Dillon, P. And Oyen, J., (eds) (2009). Building Your Canoe Basics (Chapter 6) in *Outdoor Adventures: Canoeing*. Champaign, Illinois: Human Kinetics, March.

Dillon, P. And Oyen, J., (eds) (2009). Water Safety and Survival Skills (Chapter 5) in *Outdoor Adventures: Kayaking.* Champaign, Illinois: Human Kinetics, March.

Kauffman, R., Taylor, S., and Price, R., (1991). *A Recreational Gauging and Information System to Alert Potomac River Users of Dangerous Water Levels.* Annapolis, Maryland: Department of Natural Resources, Boating Administration, Planning and Policy Program. 305 pp.

Kauffman, R. (2015). *Swiftwater Rescue Packet*. McHenry, Maryland: Garrett College. Unpublished packet.