Journal of Search & Rescue ■ Volume 1 ■ Issue 1

Time Required For a Drowning Victim to Reach Bottom

John L. Hunsucker PhD, PE
Scott J. Davison MBA, ME, NREMT-P, LP
PO Box 458, Dickinson, TX 77539
United States of America
Email: sjdavison@att.net

Abstract

This paper describes a mathematical model that can be used to provide an estimate for the amount of time a drowning victim takes to sink through the water and hit bottom, including a table for drift during the descent. A victim may be on the surface and then be on the bottom less than 10 seconds later. Search and rescue professionals need to be trained to understand the short time during which a victim can sink and drown and the need for immediate search and rescue from the bottom starting at the last point the victim was seen.

KEY WORDS: Rescue, Drowning, Lifeguarding, Body Retrieval

Introduction

How many times has a rescue squad come to a waterfront and heard the family say, "We just looked away for a second and he was gone." A common misconception is that a swimmer will stay on the surface struggling and then slowly sink beneath the surface of the water. They mistakenly believe that a witness will easily have enough time to see the drowning and make a rescue.

The purpose of this paper is to describe a mathematical model that can be used to provide an estimate for the amount of time a drowning victim takes to sink through the water and hit bottom. Since this is a model and not a full simulation, the number of variables used in the model has been limited to weight, chest circumference, chest length and water depth. Timed experiments were done by the authors in a swimming pool where one of the authors swam to about a six foot depth, expelled air, became negatively buoyant and sank to the bottom of the pool. The results of these simulations were used to check if the calculated results were close to the experimental results.

As with any mathematical model there are serious differences between the model and what actually occurs in a real situation. The intent of the model is not to arrive at an exact time but rather to show an estimation of the very short duration required while sinking. Issues which can affect the sink time include such issues as body density which differs with factors such as age and body type, current flow, and density of the water. As an example, salt water has a higher density than fresh water and therefore will have an impact on sink time. Continuing this example, a very fit twenty year old male will sink faster in fresh water than a very young female in salt water.

Since it will be shown that the time to reach bottom is relatively short (in seconds), the implication for search and rescue personnel is that a victim may be on the surface at one point in time, but be on the bottom 5-10 seconds later. Additionally, the fastest recorded drowning the authors have analyzed, i.e., time elapsed between the victim's head going under water and CPR being started immediately without the victim recovering, is 38 seconds (Hunsucker & Davison, 2010). There has been at least one other drowning documented by the authors that was less than one minute in addition to several that were felt to have been less than a minute but lacked sufficient documentation to verify the time. Unless a fellow swimmer or lifeguard, if there is one, is both vigilant and able to detect the visual signals showing a swimmer in trouble (Hunsucker & Davison, 2008) the fast drowning and sinking can make it easy to miss a victim after they disappear from the surface of the water.

It should also be remembered that, based on the laws of physics, drowning victims do not go part way down and stop once they lose positive buoyancy. They go all the way to the bottom. Emergency personnel need to be aware that drowning victims are either on the surface, moving quickly (in seconds) toward the bottom or on the bottom.

The Basic Formulas

Archimedes' principle states that a body is buoyed up by a force equal to the weight of the water that the body displaces. Since fresh water weighs approximately 62.4 pounds per ft^3 , we have the Buoyant Force, F = 62.4 lbs x V, where V is the volume of the victim in cubic feet. If F, the buoyant force, is larger than W, the weight of the victim, the victim will float. Otherwise, the victim will sink. Since the probability that they are equal is zero, a body either floats or sinks.

We make a few assumptions about the body's shape in order to build a model that can be used for estimation purposes. Suppose the chest where the buoyant force is concentrated has a height *h* and a circumference *C* and is roughly cylindrical in shape with radius *r*. This air cylinder is what we suppose changes with inhalations. Since the volume of the air cylinder decreases with exhalation, the volume will change and thus the buoyant force will change. Once we know the change in volume, we know the change in the force, then using F=ma, we can solve for the time, *t*, using elementary calculus.

The following formulas relate circumference to radius and then radius to volume for a cylinder.

Formula 1: $r = \frac{C}{24\pi}$ where *C* is given in inches and r in feet.

Formula 2: $V = \pi h r^2$ where *h* and *r* are in feet and *V* is given in ft^3

Now let C_1 and C_2 be the starting and ending circumferences of the air cylinder respectively. Here we assume that C_1 is the air cylinder circumference at the point where buoyant force and gravitation force are equal.

Then, using V for the change in volume, the change is given by

Formula 3: $V = \pi h[r_1^2 - r_2^2] = \frac{h}{\pi 24^2}[C_1^2 - C_2^2]$ in cubic feet.

So the change in force is given by 62.4 x V and also by "(m) x (a)" where m is mass and a is acceleration. So $a = \frac{32x62.4xV}{W}$ where *W* is the weight of the victim.

Letting s = the depth of the water and using elementary calculus $s = \frac{at^2}{2}$. Substituting *a* and *V* from above and solving for *t* yields

Formula 4: $t = \frac{1}{31.6}\sqrt{\frac{sW}{V}}$

Formula 5: t = $1.346\sqrt{\frac{sW}{hC_1^2 - hC_2^2}}$ where t is given in seconds.

s - Depth of the water in feet
W - Weight of the swimmer
h – Height of the chest or air cylinder in feet
C_1 – circumference of chest after inhalation in inches
C_2 – circumference of chest after exhalation in inches

Examples

The chest measurements used in these examples were done on individuals known to the authors in order to approximate the variables such as air cylinder height and the change in volume with exhalation. The reader is encouraged to measure a few people and calculate their own times

One

Suppose that the victim weighs 150 pounds, the air cylinder changes from 43 inches to 42 inches, the height of the air cylinder is 1 foot and the depth is 8 feet. Then t = 5.06 seconds.

Two

Suppose that the victim weighs 75 pounds, the air cylinder changes from 23 inches to 22 inches, the height of the air cylinder is 0.5 foot and the depth is 8 feet. Then t= 6.95 seconds.

Three

How much change in circumference will result in a 10 second descent? If we use the data in example one and suppose that the resting circumference is 42 inches, we ask how much did the chest have to deflate in order to have this time of transition. Plugging into the formula and solving yields $C_1 = 42.26\ inches$. So it would take only a quarter inch change in chest circumference to get a time as long as 10 seconds.

Four

To show a range of sink times we went to several anthropometric tables and size studies (Department of Defense, 1991) (Kuczmarski et al., 2002), (Moll & Wright, 2004), (Snyder, Spencer, Owings, & Schneider, 1975) to find typical sizes for different ages.(See Table 1) Looking at the average torso length for a male from waist to shoulder of 14.8" and an average height of 5'9" we use h=21% of height or 14.5". While not a precise measurement, this is close enough for estimation purposes. We also suppose only a 2% increase in chest size with an inhalation. This is a relatively small increase as an increase of well over 10% is common. Making these assumptions leads to the following table for estimated sink times for 8 feet deep.

Table One Estimated Time to Sink Eight Feet				
Age	Weight(lbs)	Chest Cir. (in.)	Height	Sink Time (sec)
3	33	20.2	2'9"	7.1
6	48	22.8	3'6"	6.4
12	95	28	5'	6.2
Men	180	43	5'9"	5.3
Women	148	40	5'4"	5.1

Experimental Results

Every good theory should have some applied application to verify the reasonableness of the theory. Using one of the authors as a test subject, an air tank with a long hose on a regulator was placed on the deck. The test subject weighed 240 pounds, was 6 feet tall and was in 5.5 feet of water. Enough air was exhaled until positive buoyancy was lost and the descent was timed until the bottom was contacted. This was repeated 10 times. The average time to bottom was 5.0 seconds with a standard deviation of 0.58 seconds. The times ranged from 4.0 seconds to 5.9 seconds. The variation in times is explained by the variable amounts of air exhaled resulting in variable decreases in air cylinder circumference.

For a subject whose chest decreased from 49 to 48 inches, who weighed 240 pounds and who was in 5.5 feet of water, our model yielded an approximate sinking time of 4.9 seconds. Thus we see a reasonable agreement between the theoretical and the experimental results.

Discussion

There are several factors which can cause the time to decrease. In our model, we have assumed that the body goes to the bottom in a horizontal position as what (we what) was calculated was for when the center of gravity of the body would hit the bottom. Since the center of gravity is located in the pelvic region and the center of buoyancy is located in the mid chest region, there is a turning moment placed on the body. As the body sinks, the victim will come to a more upright position as the two forces of buoyancy and gravity attempt to line up. This will cause the feet to hit the bottom first. This in essence shortens the distance to the bottom and thus the time. Once this happens, the body will gradually sink into a more horizontal position. A common sinking sequence is to have the feet contact the bottom, then the lower leg. Sometimes the torso will be slightly elevated due to the presence of air in the upper body region. The head will hang down and the arms will either sink or float up a bit depending on the physiological characteristics of the body. Over time, as air continues to evacuate the body, the body may sink to a point where most of the body contacts the bottom.

Another factor which may well shorten the time to the bottom is if water replaces air space in side the victim. If water fills the mouth, throat, lungs, stomach or any other internal air cavity of the victim, then the buoyant force will be decreased as will the time to the bottom.

This model was developed primarily around water that was eight feet deep. Deeper water would, of course, lengthen the sink time and the corresponding drift distance that the body will move. Said another way, the deeper the water and the faster the flow then the longer the drift distance and sink times.

In Table One, we assumed a minimal chest circumference loss of only 2%. Greater losses would of course account for more rapid sinking. These readings have a several implications for search and rescue.

The first implication is that any lifeguard or fellow swimmer needs to be vigilant and be able to recognize the signs that a swimmer is in trouble at the surface because once a drowning victim begins to sink, they are quickly going all the way to the bottom. Once they are on the bottom, it is difficult to determine where they are from the surface. Often, the only indications that the swimmer is on the bottom (if you can see the bottom) is a color variation, (This is referred to as a “smudge”, since water variables such as glare, clarity, surface action, or siltation tends to mute colors and distorts shapes. Only under the best of circumstances will a victim on the bottom appear to be a person or will different colors be obvious – hence a subtle color variance, a smudge), the patient’s body in a temporary tilted position with knees on the bottom (again, if the water is clear enough to see a body), small bubbles at the surface, or a vomit stream at the surface.

The second implication for search and rescue is that the very quick transition from on or near the surface to the bottom means that the victim’s body is less likely to drift or move far away. Even in a current, once the victim comes to a hole or eddy, they tend to stop. Holes and eddy’s on the bottom of lakes and rivers tend to keep what is in them. This implies that the victim has a good chance of being found on the bottom at or close to the place they were last seen on the surface. One exception to this is if a victim falls into a storm sewer or man-made flood system where there is a lot of moving water and smooth sides and bottom. The body then tends to roll and may end up far downstream. The same situation can occur with the extreme current flows often found in flooding situations.

The third implication is that the current in a river can move the body downriver while it is sinking to the bottom. Lakes and swimming pools don't normally have currents. Many recreational rivers only have a current of 2-3 miles per hour while a fast river may reach 6-7 mph. A fast stream may only be flowing at less than 1 mph. (Marietta, 2012) The rapids above Niagara Falls run about 25 mph. (Niagara Parks, 2012) You can estimate how many feet a body might move in a river if you find the speed of the current and multiply by the number of seconds the body takes to sink. The conversion from miles per hour to feet per second can be done by multiplying miles per hour by 88 and then dividing by 60. Table 2 shows how far a body may move in various currents during the descent. As an example, in a fairly common flow of 2 mph, a body will move between 11.7 and 20.5 feet downriver before contacting the bottom, assuming a 4 to 7 second sink time. Once the bottom is contacted, downriver movement will be minimized by irregular bottom contours. Regardless of the current flow, Table Two emphasizes the point that body searches should begin in the immediate vicinity of the best estimate of the point the victim was last on the surface.

Table Two
Distance (ft.) moved during descent for various currents

		Speed (mph)						
		1 mph	2 mph	3 mph	4 mph	5 mph	6 mph	7 mph
Time (sec)	1	1.5	2.9	4.4	5.9	7.3	8.8	10.3
	2	2.9	5.9	8.8	11.7	14.7	17.6	20.5
	3	4.4	8.8	13.2	17.6	22.0	26.4	30.8
	4	5.9	11.7	17.6	23.5	29.3	35.2	41.1
	5	7.3	14.7	22.0	29.3	36.7	44.0	51.3
	6	8.8	17.6	26.4	35.2	44.0	52.8	61.6
	7	10.3	20.5	30.8	41.1	51.3	61.6	71.9
	8	11.7	23.5	35.2	46.9	58.7	70.4	82.1
	9	13.2	26.4	39.6	52.8	66.0	79.2	92.4
	10	14.7	29.3	44.0	58.7	73.3	88.0	102.7

Many search and rescue organizations have recognized this phenomenon. For example, see Cynthia Garfold's article on "The Biology of Drowning" from the Western Pennsylvania Search and Rescue Development Center for an excellent description of how and why bodies tend to stay close to where they went below the surface. She wrote, "When a drowning occurs in a river, the most common mistake is to search for the body too far downstream." (Garfold, 2009)

However, there are many factors which could increase this drift by significant orders of magnitude. Two of the factors which will have a major impact are current flow and river contour. Extreme currents such as those encountered in a flooding or even in naturally flowing rivers have been known to move bodies miles from the location of the actual initial immersion. In addition, a smooth bottom or regular bottom such as found in a channelized flow produces little, if any, bottom eddies that will slow the drift of a victim. There are numerous examples of drowning that can be found in the press that show the impact of extreme current on drift. For example: 1) Lake–"yards away" drift (The Times-Picayune, 2012), 2) Lake–"near" drift (WishTV, 2012) 3) River–"250 yard" drift (DesMoines Register, 2012) 4) River–"approximately 300 yards drift" (Fox19, 2012) 5) River–"quarter mile" drift (Associated Press, 2012), 6) River-"two mile" drift (Seattle Times, 2012).

Conclusion

While this model does not yield a formula that shows as precise a time as a more sophisticated simulation would, it does show an approximate estimate of the time to the bottom. More importantly, it shows that the time to sink to the bottom is fairly short. Different combinations of variables show times of less than 7 seconds for sinking and only extremely small chest size changes could increase the time to as long as 10 seconds. This model provides an estimate of where to begin the search. Other factors such as water depth, current flow, body type, and water density should be considered which may lengthen the sink time and promote extended movement of the body.

The major implication for search and rescue and for body retrieval is to initiate the search at the point where the victim was last estimated to be at the surface.

References

Associated Press. (2012). *Searchers find body of student in Colo. River* Retrieved from http://www.ksl.com/?nid=148&sid=20772669

Department of Defense. (1991). *Military handbook anthropometry of U.S. military personnel* (Metric), DOD-HDBK-743A, Retrieved from http://www.dtic.mil/dticasd/anthro.html

DesMoines Register. (2012). *Firefighters find Cedar River drowning victim.* Retrieved from http://www.desmoinesregister.com/viewart/20120522/NEWS/120522011/Firefighters-find-Cedar-River-drowning-victim

Fox19. (2012). *UPDATE: Crews recover body of Great Miami drowning victim*. Retrieved from http://www.fox19.com/story/18650996/crews-resume-search-for-man-missing-in-great-miami-river

Garfold, C. (2009). *The Biology of Drowning, Western Pennsylvania Search and Rescue Development Center*. Retrieved from http://www.operationtakemehome.org/sar/Fire%20and%20Rescue%20Personnel/Biology%20of%20drowning.pdf

Hunsucker, J., Davison, S. (2008). *How Lifeguards Overlook Victims: Vision and Signal Detection*. International Journal of Aquatic Research and Education (IJARE), *2*(1), 59-74

Hunsucker, J., & Davison, S. (2010). *Development of in-water intervention (IWI) in a lifeguard protocol with analysis of rescue history.* International Journal of Aquatic Research and Education*, 4*(2), 186-198.

Kuczmarski, R, Ogden, C, Guo, S, et al. (2002). 2000 CDC growth charts for the United States: Methods and development. National Center for Health Statistics. Vital Health Stat 11(246).

Pharmaceutical Benefits Branch, Australian Government Department of Health and Ageing. (2004). *Chest Expansion Normal Data*, Retrieved from http://www.medicareaustralia.gov.au/provider/pbs/drugs1/files/ma_chest_expansion_normal.pdf

Marietta College (2012). Marietta College Department of Biology and Environmental Science's Biomes of the World, Found in streams and other aquatic habitats: Rivers and streams, Retrieved from http://www.marietta.edu/~biol/biomes/streams.htm

Niagara Parks. (2012). *Niagara Falls Geography: Facts and Figures*. Retrieved from http://www.niagaraparks.com/media/geology-facts-figures.html

Seattle Times (2012). *Searchers find woman's body in Green River*. Retrieved from http://blogs.seattletimes.com/today/2012/06/searchers-find-womans-body-in-green-river-2/

Snyder, R.G., Spencer, M.L., Owings, C.L., Schneider, L.W. (1975). *Physical characteristics of children as related to death and injury for consumer product safety design*. Consumer Product Safety Commission Report UM-HSRI-BI-75-5, Retrieved from http://ovrt.nist.gov/projects/anthrokids/child.html

The Times-Picayune (2012). *Family finds body of teen who dove into Lake Pontchartrain.* Retrieved from http://www.nola.com/traffic/index.ssf/2012/04/family_finds_body_of_teen_who.html

WishTV. (2012). *Divers find body of missing man in Lake Shafer*, Retrieved from http://www.wishtv.com/dpp/news/local/dnr-divers-search-for-man-in-lake-shafer1339098892530