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PAPER

GENERAL

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K9 Water Searches: Scent and Scent Transport Considerations

ABSTRACT: Increased use of water search dogs for detecting submerged bodies has created the need for a better understanding of scent emanating from the bodies and how it transits the water to the dog's nose. A review of recent literature identifies likely scent sources, potential scent transport processes, and research needs. Scent sources include gases in bubbles or dissolved in the water, liquids as buoyant plumes and droplets or dissolved in the water, and solids consisting of buoyant particulates with secretions, bacteria, and body fluids. Potential transport processes through the water include buoyancy, entrainment, and turbulence. Transport processes from the water surface into the air include volatilization and evaporation enhanced by bubble bursting, breaking waves, splashing, and wind spray. Implications for the use of water search dogs are examined. Observations of submerged, decomposing bodies are needed to quantify the physical and chemical characteristics of the scent and scent transport processes.

KEYWORDS: forensic science, canine scent detection, canine water search, underwater decomposition, cadaver, water searches

The use of search dogs in the USA to detect submerged bodies was predated by the Navy's waterdog program that began in 1968 (1). This program was designed to test the use of dogs for protecting assets (boats, bridges, docks) in river and inshore environments from attack by surface, snorkel, and open-circuit SCUBA swimmers. The dogs were successful in detecting swimmers on the surface and underwater and were deployed in Vietnam. The idea that the Navy's methods could be developed into a water search technique for drowned subjects culminated in a National Association for Search and Rescue (NASAR) conference report (A. Stanley, personal communication, 1981) that discussed eight cases where dogs were utilized to locate drowned victims. By the mid-1980s, water search dog training programs were devised (2) and several search dog groups were using their dogs to locate drowned subjects (2–5).

A number of hypotheses have been proposed about the nature of the scent the dogs were detecting, its dissolution in water, and its transport to the surface (M. Hardy, personal communication, 1984; [6,7]). Recent studies have improved our understanding of the nature of scent emanating from cadavers on land and of potential processes for transporting scent and scent-bearing materials through the water and into the air. With increased use of water search dogs by recovery agencies, there is a need to have a better understanding of scent and scent-bearing materials given off by submerged bodies and how these reach the dog's nose.

At the outset, it must be admitted that our understanding of the nature of scent, scent-bearing materials, and scent transport processes in water is incomplete. Consequently, it is not possible to state with certainty the nature of all scent sources, transport processes to the water surface, behavior of scent on the surface, how the scent gets into the air, and what it is that the dog smells. However, there is an extensive literature on the behavior of gases, liquids, and solids in water that can be used to improve our current understanding. This paper reviews the literature, identifies likely sources of scent and scent-bearing materials from submerged bodies, and suggests potential transport processes from bodies through the water to the air–water interface and thence into the atmosphere. The information is used to examine hypotheses about human scent in water, transport processes, and implications for water search dog training and deployment. Realistically, it can only serve in the interim until data from research specific to submerged human bodies is available. Only submerged bodies will be considered since these are the cases where water search dogs are most commonly used.

The Body in Water

The body in water experiences forces that cause it to weigh less than in air, change shape and density, and move about in three dimensions in space. One cubic foot of freshwater weighs about 62.4 lb (at 32–60°F, 64.1 lb for seawater) and the pressure on its bottom surface is 0.433 psi (62.4 lb/144 in.^{2}). For a column of water of height (or depth), d (feet), the pressure at its bottom is $0.433 \times d$ ($0.445 \times d$ for seawater). At a point at depth, d, this pressure acts equally in all directions. There is a misconception that water pressure "holds" a body down (i.e., there is a net downward force on the body). However, the above discussion indicates that the pressure at the top of a body is less (the depth is less) than at the bottom of it where depth is greater. This indicates that the body experiences a net upward pressure or force. According to Archimedes principle, this force is equal to the weight of the water it displaces. Thus, the effect of pressure on the body is to buoy it up rather than to "hold" it down.

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Another effect of pressure on a body is to compress it into a smaller volume increasing its density. The reduced volume decreases its buoyancy so that body weight increases with depth. Underwater weights of about 100 bodies to depths of 100 ft showed that there was a small increase in weight with depth (8). While the details of the experiment are not available, it suggests that an increase in pressure of about 18 psi produced an increase in weight of about 2 lb which corresponds to the weight of about 55 in.^{3} of water. The weight and depth distribution of the subjects is unknown and could cause an error in this estimate. The experiment also showed that adults who weighed from 110 to 200 lb weighed 7–16 lb underwater. This weight was sufficient to resist movement by currents <1.5 mph (2.2 ft/sec). However, water velocity decreases close to the bottom and the depth where this velocity was measured was not stated.

Generation of decomposition gases in the body cause its volume to increase which displaces more water increasing its buoyancy. The expanding body may eventually attain neutral buoyancy (zero weight) and then positive buoyancy causing it to rise. As it rises, decreasing pressure allows the body to expand further increasing its buoyancy and accelerating its ascent to the surface. For the subjects in the above experiment (8), neutral buoyancy requires decomposition gases to expand the body volume by 0.11–0.26 ft^3 (7–16 lb/62.4 lb/ft^3) or about 190–440 in.^{3}.

In the approximation that the ideal gas law holds for decomposition gases, neutral buoyancy requires:

$$P \times \Delta V = R \times T \times \Delta n \tag{1}$$

where P is the pressure, ΔV is the change in body volume, R is the universal gas constant, T is the temperature, and Δn is the amount of gas required to make the body neutrally buoyant. For the above experiment (8), $\Delta n \sim 0.6$ mol at a depth of 100 ft and temperature of 45°F. Equation 1 shows that Δn is a function of $P \times \Delta V/T$ so that as P increases (at greater depths), Δn increases (more gas is required) and as T decreases Δn increases. Recovery operations for drowned subjects show that some bodies never float. This suggests that, for a given T, there is a maximum pressure that the decomposition gases can develop or that Δn is limited. Bodies at depths of 180 ft (about 78 psi) may never achieve flotation (9). Anecdotal evidence from some search dog handlers and divers experienced in body recovery put this depth at 100 ft or less where the pressure is on the order of 40 psi.

In lakes with currents and in streams, the body may move before neutral buoyancy has been attained. For velocities <1.5 mph, some buoyancy must be attained before the body moves (8), but for higher velocities the body can move without an increase in buoyancy. In analogy with observations of the movement of anchor ice weighted with sediment but almost neutrally buoyant (10), the body would be expected to bump along the bottom until buoyancy is neutral and then rise as the buoyancy increases further. Body damage associated with movement by currents or wave action has been described (8,11,12).

Water temperature controls water density, and therefore buoyancy, but its primary effect is to influence buoyancy through decomposition. However, decomposition gas production does not significantly influence buoyancy of bodies submerged for <12 h at 60–65°F, <24 h at 50–60°F, and <48 h at temperatures colder than 50°F (8). It is not possible to use these results to predict flotation since other factors may be involved including both physical (clothing, shoes, amount of weight carried for activities, weight carried by homicide or suicide victims) and biological (composition of last meal, amount of fatty tissue, decomposition stage).

The Body in Water as a Scent Source

The body is the source of a host of scent materials that are available for the water search dog to detect. Dogs cannot smell a body through the water but scent and scent-bearing materials from the body can enter the water, rise through it to the surface, and enter the air to be detected by them. However, there does not appear to be information on the nature of the scent or scent-bearing materials emanating from submerged decomposing bodies. Consequently, this information must be inferred from studies of living humans, decomposing bodies in the terrestrial environment, bodies recovered by divers in recovery operations, those found floating or washed ashore, submerged pig carcasses, and water search dog training aids. For living human bodies, exhaled air and volatile organic compounds (VOCs) from the skin produced by glandular secretions on the skin and skin rafts and from hydrolysis and microbial degradation of these secretions have been implicated as human scent components (13–17). VOCs from buried decomposing bodies have been identified (18–20). These components may be soluble or insoluble in water and denser or less dense than water. Water may modify them and accelerate or retard decomposition depending primarily on its temperature, availability of oxygen, and whether it is salty or fresh, moving or still, or differs from normal pH (9). The presence of scavengers and other factors can also be important (8,11,21,22).

Decomposition stages generally include fresh, early, advanced, and skeletonization with some classification differences between observers (11,21–24) and are similar to those for pigs (22,25,26). These studies indicate that most bodies will be submerged twice, once on drowning prior to bloating and once after decomposition gases have been released. Some bodies never float and some never sink, especially infants (8), prior to recovery.

The postdrowning timeline for scent sources is strongly influenced by water temperature through its effect on decomposition. At temperatures in the 30s°F, decomposition may be so slow that internal gas production is not sufficient to float the body for months while, at temperatures in the 80s°F, the body may float in a day or two (8).

Consideration of training aids that dogs are known to detect can aid in the identification of potential scent sources from a submerged body. Dogs can detect submerged clothing and shoes (7), possibly from VOCs in the items as a result of contact with the skin. Some handlers use human hair that is normally covered with glandular secretions as a training aid. Fingerprints consist of water, soluble compounds, and insoluble compounds modified by hydrolysis and bacterial degradation that include VOCs that have been implicated in human scent (14,16). A single fingerprint on a slide immersed in water produced an oil film on the water surface within a few minutes (27) although the transport process remains unknown. Human bones produce VOCs (20) and have been used as training aids that are detectable by water search dogs.

This discussion of potential scent sources starts with the time of drowning. For searches conducted soon after the event, dissolution of VOCs from the skin and insoluble oily residues from secretions may be important. Vomitis, feces, urine, and existing intestinal gases purged as a result of muscle relaxation have been implicated (8,11). Injuries to skin, tissue, and bones (from homicides, suicides, propellers, body movement as a result of currents or wave action, and scavengers) can produce body fluids and particles of skin, tissue, and bones (8,11,21,22,25,26). Studies of pig carcasses show that scavengers may cause body fluids and particles to be released throughout the period of submergence and especially when the body rests on the bottom (25). Blood, foam, and blood-stained foam have been observed coming from the mouths and nostrils of recent drowning victims, apparently due to lung damage caused by agonal gasps during drowning (8). A bubbly, malodorous, brownish green, blood-stained fluid has been observed coming from the mouths of drowning victims as a result of pulmonary autolysis (8).

Micro-organisms associated with putrefaction convert soft tissue to simple molecules, gases, and liquids (18). Gases produced in the bowels and other parts of the body during putrefaction include hydrogen sulfide, carbon dioxide, methane, ammonia, sulfur dioxide, and hydrogen. Tissues are converted to volatile fatty acids and other compounds including putrescene and cadaverine that were formerly used to train cadaver dogs (18). Gases and fluids in the intestines and lungs purge from the rectum, mouth, and nostrils. Accumulation of decomposition gases in body cavities and/or in soft tissues can lead to flotation (8,9,11,28). The remains float until they lose their putrefaction-produced buoyancy and then sink.

Shedding of hair, nails, and skin sloughing occurs (11,22). Saponification (formation of adipocere, a malodorous, cheesy, compound of fatty acids) retards decomposition (8). Adipocere can persist for long times, particularly where the body is covered (clothes, dive suit). A diver recovered from a depth of 886 ft after 10 years had skeletonized hands and head that were exposed to the water but his body inside the dive suit had saponified and still produced a strong smell (29). Internal organs may remain in a semi-liquid state (8). Eventually the body will be skeletonized with the remains often partially covered by clothes and flesh and partially held together by greasy connective tissue (8,11,22). Disarticulation follows with the potential for separation of bones by currents and wave action (11,12).

The above limited survey of the fate of submerged human remains indicates that scent sources from submerged bodies include gases (dissolved and in bubbles), liquids (plumes and droplets of body fluids, secretions, and decomposition fluids), and solids (particles of skin, tissue, bones, feces, vomitis) that may be encountered in a search for these remains. These materials have been shown to consist of or have associated VOCs that may be detected by search dogs. It seems clear that the training of a water search dog should include scent sources covering the full range of decomposition including the fresh stage immediately after drowning (20). Common deployment times for water search dogs range from a few hours to months after a known drowning and at random and sometimes much later times for missing persons, homicides, and suicides. There are observations of the successful use of dogs months and even years after the occurrence of a drowning ([30]; Osterkamp, unpublished).

Scent Transport Processes

The above considerations indicate that the body produces scent materials in all the common phases of matter (gases, liquids, and solids) and the physical characteristics of these materials, particularly phase and density (buoyancy), suggest specific scent transport processes. Local hydrodynamic conditions, especially turbulence, also play a role. Studies of hydrocarbon seeps in the seabed, gas transfer at air–water interfaces, and ice formation in freezing streams provide insight into the characteristics of these processes. Potential transport processes available to move the scent sources to the water surface and into the atmosphere are examined below.

Gases

There do not appear to be any measurements or observations of the gases emanating from a submerged body but it seems likely that these would be much the same as those from a decomposing body in the terrestrial environment (18–20). Decomposition gases, foam, and bubbly fluids observed coming from the mouths and nostrils of bodies (8), and bubbles released from clothing would be examples of gases containing VOCs. Since decomposition gases are soluble in water (9), potential gas sources are dissolved VOCs and gas bubbles.

Potential scent transport processes for dissolved VOCs to the water surface include molecular diffusion, turbulent diffusion, and entrainment in an upward flow of bubbles, buoyant liquids, and solids. However, molecular diffusion is extremely slow leaving turbulent diffusion and entrainment. Once the dissolved gases reach the surface, volatilization is the most likely pathway for scent transport into the air above the water surface (31).

Investigations of shallow submerged hydrocarbon seeps (<70 m water depth) provide some insight into the nature of gas bubbles and their transport to the water surface. The seeps release gases as bubbles that may be oil coated and oil as droplets that rise to the surface because of their buoyancy and local hydrodynamic conditions (32–34). The gases released were primarily methane but also included carbon dioxide, and trace gases such as hydrogen sulfide, some of the same gases produced during decomposition. As methane bubbles rise, they exchange gases with the surrounding water, dissolve as methane outflows, grow as dissolved air (nitrogen and oxygen) inflows, and expand due to decreasing hydrostatic pressure (33). Bubble rise velocities typically range up to ~1 ft/sec for large (>0.07 in. diameter) bubbles (32).

When gas bubbles reach the surface, bursting occurs. Upon bursting, the bubbles leave an oil sheen on the water indicating that they contain oil (32). Bursting gas bubbles can eject bubble contents (gases and droplets from the inside surface of the bubbles) into the air to a height of ~1 ft above the water surface (35). Breaking waves, splashing, and wind spray can enhance gas transport into the air (36).

The above studies suggest that decomposition gases and some fluids may be transported to the water surface by bubbles. Bubble bursting at the surface, enhanced by breaking waves, splashing, and wind spray, would eject gases and water droplets into the air above the water surface and leave a film of volatile fluids on the water surface. It would then be possible for dogs to detect the gases in the air and any evaporate from the films.

In lakes, bubbles rise to the surface in close vertical proximity to the source influenced by waves and near-surface turbulence (32–34). In flowing waters, the bubbles rise to the surface at a position downstream of the source. A criterion for layered versus well-mixed flow in streams has been developed (37) that combines the competing time scales for buoyancy and vertical turbulent diffusion. Application of this criterion shows that, except for very small bubbles (<0.01 in. diameter) with small rise velocities, the flow would be expected to be layered (i.e., the bubbles would rise to the surface and burst putting scent into the air). Exceptions would be small bubbles with very small rise velocities and/or streams with steep bed gradients and large flow velocities where the flow would be highly turbulent and the bubbles well mixed vertically in the flow.

Liquids

Urine and blood consist of organic and inorganic solutes dissolved in water with some volatile compounds. They are heavier than water and should sink in water. Blood also contains cells and platelets that are heavier than water. These considerations and dilution by water suggest that urine and blood may not be significant scent sources except under special conditions. For example, these may include entrainment in a buoyant flow of other scent materials and vertical mixing in turbulent flow.

Studies of submerged seeps give some insight into transport processes for buoyant, insoluble body and decomposition fluids to the water surface and for their volatile components into the atmosphere above the surface. Oil released from seafloor vents rises to the surface through the water column although droplet rise velocities are much slower than bubbles unless entrained in an upwelling with gas bubbles (32). As oil droplets rise, the more volatile components dissolve in the water, and, on reaching the surface the oil spreads in a thin film.

Skin secretions, body and decomposition fluids, and other fluids (from the lungs and gastrointestinal tract, broken skin blisters, other skin ruptures, from greasy bones and other remains) are generally lighter than water. The seep studies indicate that oily fluid plumes and droplets of these scent-bearing materials would rise to the surface because of buoyancy spreading there in a thin film. Dissolved gases may rise to the surface by turbulent transport and by entrainment when in close proximity to the buoyant droplets and plumes. Scent can be transported into the air by evaporation of the film and volatilization enhanced by breaking waves, wind spray, and splashing.

In lakes and water bodies without currents, oil droplets and plumes would rise to the surface in close vertical proximity to the body (lateral dispersion is small) influenced only by waves and near-surface turbulence. In streams and water bodies with currents, droplets and plumes would rise to the surface at a position downstream from the body. Using the criterion for layered versus well-mixed flow (37), the droplets would be expected to be well mixed vertically in the flow, except for small flow velocities (<1.6 ft/sec) and/or very large droplets.

Solids

Particles of vomitis, feces, skin rafts, skin, bone, and tissue may be transported to the surface because of their buoyancy and turbulent diffusion. These particles have secretions, bacteria, and various body fluids on them that produce VOCs. Dissolution of the VOCs in the water, transport to the surface by entrainment and turbulence, and volatilization at the surface would create a gas flux into the air. Some of the secretions and body fluids may be transported to the surface as plumes or droplets and into the air by volatilization and evaporation. On reaching the water surface, the associated volatile components on the surfaces of the particles may be transported into the air by evaporation. Larger particles would have faster rise velocities because of their larger Archimedes force but the rise velocity also depends on the shape of the particles. For particles with a disc-like shape, about 0.04–0.2 in. in diameter, and density about that of ice, the rise velocities would be expected to be in the range from 0.1 to 0.8 in./sec (37) and, for skin rafts, <0.04 in./sec. Transport of volatiles into the air would be enhanced by surface water dynamics (breaking waves, wind spray, and splashing).

Special Considerations in the Use of Dogs for Water Searches

Lateral Displacement of Scent in Lakes and Streams

Dogs detect scent in the air above the water surface after the scent has been subjected to prevailing winds and atmospheric conditions. If the dog handler and boat operator are skillful, they can use the dog and knowledge of wind conditions to determine the approximate position where scent from the body exits the water. The question remains as to the body position in the water. Under quiet conditions, as in a lake, buoyant scent materials will rise vertically from the body to the water surface because lateral dispersion is small. For lakes with through flow, tidal areas, or streams let v be the rise velocity of the scent that is determined by the scent material. The time to rise through a depth, d, is d/v and the scent would be transported a distance, $x = u \times (d/v)$ downstream, where u is the mean velocity of the water, before reaching the surface. If d and v are known, a rough value of x can be obtained from a visual estimate of u. For example, for large gas bubbles with $v = 1$ ft/sec, $d = 20$ ft, and a stream moving at a slow walking speed ($u \sim 1.5$ ft/sec), $x \sim 30$ ft. For fast turbulent streams (about 3 mph or more), the calculation is more complex since the time to rise through a depth, d, is $d/(0.134 \times u^*)$, where u^* (the friction velocity) must be calculated from the water slope and hydraulic radius. However, for some flow conditions (very turbulent, horizontal and vertical eddies adjacent to shores and behind obstructions in the flow, downstream from dams) scent may rise to the surface close to the position of the body.

Thermoclines

A thermocline is a horizontal zone or plane of water found in a lake during the summer stratification that separates warm well-mixed water near the surface from colder stagnant water below. At present, it is thought that scent from a submerged body on a lake bottom is transported to the surface by diffusion and therefore cannot penetrate the thermocline (6,7). This belief has given rise to the idea that it is best to search for submerged bodies in the fall, winter, and spring in the absence of thermoclines and has also been used to explain failures of dogs to detect bodies in the presence of thermoclines. However, the transport processes for gases in bubbles, liquid plumes and droplets of oily material, and buoyant particulates are driven by buoyancy which would readily transport scent-bearing material through the thermocline to the surface. Problems with the performance of water search dogs where thermoclines exist must be a result of other unknown factors.

Scent Pooling at the Surface

There is anecdotal evidence that, if the air temperature is colder (35°F or below) than the water, scent pools at the water surface and does not get airborne requiring dogs to swim to detect it (6). However, air in contact with the water under these conditions would be warmed by the water, making it lighter and unstable causing convection in the air above the water surface. The convective layer would mix air, water vapor, and scent emerging from the water surface into the atmosphere (this can sometimes be observed as a layer of fog with thickness of several feet or more). Also, gas bubbles that burst at the water surface eject their contents (water droplets and gas) into the air with water droplets reaching heights of 1 ft. Wind (even a light breeze) would enhance evaporation and further mix scent into air near the water surface. Thus, the thickness of the scent layer above the water surface is likely to be on the order of feet or more making it possible for a dog to detect it from a boat under the above conditions.

Summary and Research Needs

The increased use of water search dogs by recovery agencies for detecting submerged bodies has created the need for a better understanding of scent and scent-bearing materials emanating from bodies and how these transit the water to the dog's nose in the air. Coincidentally, information on scent and scent-bearing materials associated with bodies on land and on potential geophysical processes for transporting these materials through the water and into the air has improved significantly over the last two decades. This review identifies likely scent sources, potential scent transport processes, and future research needs.

Scent sources from submerged bodies include gases (dissolved and in bubbles), liquids (plumes and droplets of body fluids, glandular secretions, and decomposition fluids), and solids (particles of skin, tissue, bones, feces, vomitis). These materials have been shown to consist of or have associated VOCs that may be detected by search dogs. Potential scent transport processes for dissolved VOCs to the water surface are turbulent diffusion and entrainment in an upward flow of other scent material. Volatilization at the water surface appears to be the most likely pathway for scent transport into the air. Gas bubbles, liquids, and solids may be transported to the surface by buoyancy, turbulent diffusion, and entrainment. Bubble bursting at the surface would eject gases and water droplets into the air above the water surface and leave a film of volatile fluids on the water surface. VOCs may be transported into the air by evaporation of the film and volatilization. Oily fluid plumes and droplets of these scent-bearing materials would rise to the surface because of buoyancy spreading there in a thin film. Solids may be transported to the surface because of their buoyancy and by turbulent diffusion. These have secretions, bacteria, and various body fluids on them that contain or produce VOCs that can be transported into the air by volatilization and evaporation. Transport of VOCs from the water into the air may be enhanced by breaking waves, wind spray, and splashing.

The effect of water pressure on a body is to buoy it up rather than to "hold" it down. In water without currents, the body scent materials would rise to the surface almost directly over the body. In streams, the scent materials would surface at a distance downstream. Thermoclines in lakes are not barriers to scent transport to the water surface. The thickness of the scent layer above the water surface is likely to be on the order of feet or more making it possible for a dog to detect it from a boat.

Future research is needed to improve our understanding of scent and scent-bearing materials emanating from bodies in water. Studies are needed covering the full range of decomposition (hours to years) and the effects of water temperature, chemistry (especially oxygen levels, pH, salinity), and flow conditions. Quantitative information on decomposition gases and VOCs coming from submerged bodies such as types, amounts, and timeline for occurrence do not exist. Bubble rise velocities are known for several gases but depend on the bubble size and these are not known for submerged bodies. The fate of skin secretions when submerged is not known. Quantitative information on the timeline for occurrence, amounts, physical characteristics (size, shape, and density), and rise velocities of particulate scent-bearing materials does not appear to exist. Rise velocities are important for recovery operations. Measured transport rates of scent materials into the air and the effects of bubble bursting, turbulence, wind, and waves on them are also lacking.

Information from these types of studies would help K9 handlers select improved training aids and search protocols that would improve their performance in locating drowned subjects for recovery agencies. Such information could also be used to develop an "electronic nose" (19,20,38) for water search applications.

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