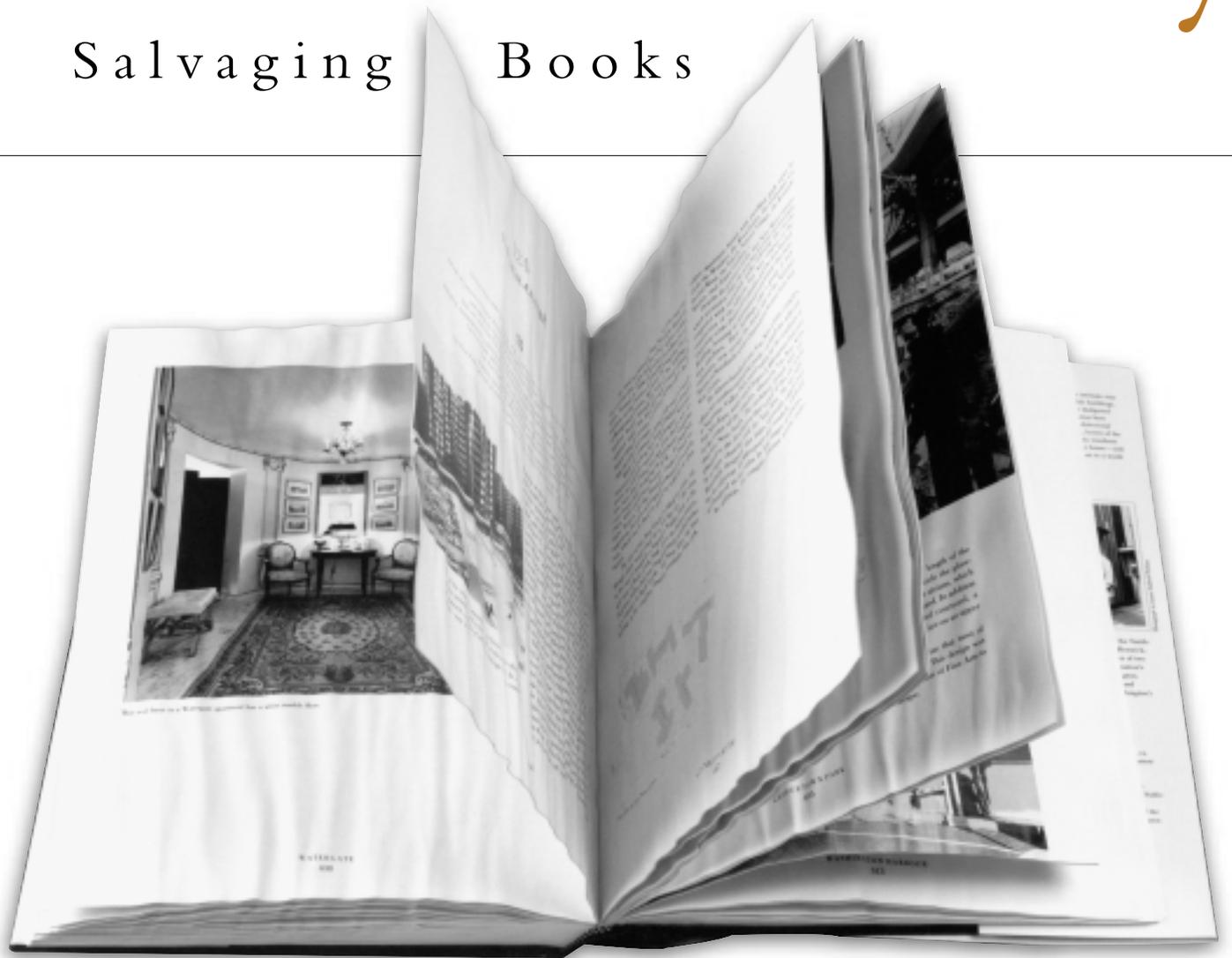


Disaster Recovery

Salvaging Books



Every cultural institution, most offices, and many private homes house collections of books. Many of these collections will experience a water catastrophe, large or small, at some time. Small emergencies—a leaking pipe or roof, or a flooded basement—are the most prevalent and easily contained. Whether the emergency is large or small, however, a quick response is essential to fully salvage wet volumes.

This technical bulletin reviews the range of effective options for drying wet books. For a successful recovery, it may be important to seek the advice of a book conservator or a specialist in library preservation, especially when rare books or large collections are damaged.

DISASTER PREPAREDNESS

A disaster, by definition, is an unforeseen event. So, how do you prepare in advance?

First, know your collection. Valuable collections should be cataloged and a copy of those records should be kept off-site. Even working collections in offices have essential records that cannot easily be reproduced. These should at least be inventoried and the locations of crucial books and documents recorded.

Second, assess your vulnerability to disaster. Be sure to keep routine building maintenance up to date. Establish a schedule for checking the roof and building systems—

plumbing, gutters and drains, electrical systems—and stick to it. Be careful also to store collections in ways that will protect them from danger. For example, do not put bookshelves beneath overhead pipes or in attics, and never leave books stacked on the floor. Individual housing for special books, such as rare-book boxes, can help protect books; even polyester film slipcovers can provide essential protection in some disasters.

Third, keep supplies on hand for emergency recovery. Basic equipment and supplies for cleaning wet shelves and removing standing water include rags and water vacuums; crates, packing supplies, and hand trucks for removing wet books from the site; and precut plastic sheeting and tape to cover shelves and divert water.

Advance consideration of supply needs and recovery logistics can save significant time in an emergency when delays can be costly. For instance, a supply of self-supporting boxes (such as plastic crates) can be crucial as a backup when cardboard boxes fail because of the weight of wet books. Plastic sheeting can be precut to fit the size of shelves. Identifying a packing area convenient to a loading dock, and also testing the transport routes through a building, are two other important steps in disaster preparedness planning.

Fourth, prepare a written emergency response plan. A written emergency plan is essential for every institution. The plan should begin with step-by-step procedures to protect staff and visitors in case of any unforeseen event, including power failures, medical emergencies, security emergencies, and damage (small- or large-scale) to the facility. The second section of the plan should discuss recovery procedures for staff—including damage assessments, inventorying of damaged materials, contracting services, and risk management—with responsibilities

for each part of the process assigned to specific staff members. A number of institutions have adopted an emergency-response-team model approach that assigns team leaders the responsibility of directing each aspect of the recovery. For further information on emergency response planning, see the accompanying selected bibliography.

PLANNING THE RECOVERY

Depending on the extent of the disaster, the best overall plan for wet books typically uses a combination of approaches. For example, three drying methods may be used to respond to a single event: (1) Several very wet volumes and books with coated paper stock may be frozen for vacuum freeze-drying; (2) A few slightly wet volumes may be air-dried in a room unaffected by the water damage by fanning open the books on tables with electric fans to speed evaporation; (3) Steps can be taken to reduce the humidity and increase air circulation in the stacks to dry damp and slightly wet volumes on shelves. When planning the recovery, it's important to keep in mind that often there is no one "best solution"; instead, several different methods may be the answer.

When choosing a method for drying a wet book, you are trying to avoid two main problems: physical damage and solubility effects. Both categories include damage that can occur during the initial wetting, during prolonged water exposure, or in drying.

Physical damage begins with the absorption of water. Books can absorb large quantities of water—paperboard covers and cloth can absorb even greater quantities than paper in terms of weight per unit volume. Varying patterns of damage result from different wetting of text and covers, which can cause damage during both the wetting and drying stages. For instance, expansion can lead to damage at the wetting stage, while shrinkage and differential drying can result in damage, or at best unsatisfactory results, in the recovery stage.

Solubility effects can cause damage to the paper or media. When paper is wet, the paper fibers swell, causing the sheet to expand. If the paper is old and yellowed, brown degradation products (from oxidized cellulose and paper additives) can form dark "tidelines" as the paper dries. If the sheet is not pressed and flattened properly, it will dry distorted and "cockled." If a

paper contains soluble media or surface coatings, the colors will "bleed" and the coating may wash away or cause sheets to stick together. Some damage can thus occur during either the initial wetting—with bleeding of ink or media—or in the drying phase—with the formation of tidelines and the "adhering," or "blocking" of coated papers.

RECOVERY OPTIONS: AN OVERVIEW

Books and all materials dry in one of two ways: *evaporation* or *sublimation*, depending on the state of the water before it passes to vapor and escapes from the materials. Water in the wet state will evaporate. Water in the solid state—ice—will sublimate (freeze-dry) under the right atmospheric conditions.

Evaporation Three techniques are generally used for drying books by evaporation: *natural air-drying, dehumidification, and application of heat by vacuum-drying or thermal-drying*. As a rule, evaporation-drying is more likely to result in some residual damage to a book after drying. This is because all evaporation-drying relies on capillary action to carry the water to the surface of the page or cover before the water turns to vapor. All of the damage described as solubility effects can occur during evaporation: tidelines, distortion, bleeding, and blocking.

Sublimation Also called freeze-drying, sublimation occurs when, under the proper temperature and pressure, ice passes directly to the vapor state, by-passing the wet state. Sublimation offers good overall results and has several advantages, the key one being its ability to remove water directly from books in a solid ice state. By thus avoiding the damage that liquid water can cause, solubility issues such as bleeding and tidelines are circumvented. Sublimation is clearly the best way to dry coated papers. Drying by sublimation also avoids shrinkage; however, books still need to be pressed during sublimation to dry flat. Sublimation still has potential pitfalls, the most common problem being embrittlement from overdrying during vacuum freeze-drying.

Drying by Evaporation

Evaporation at its most basic—fanning books open to dry, what this bulletin calls "natural air-drying"—has been termed *uncontrolled drying*. This is true, to the extent



Air-drying book. Note the characteristic cockling of pages and tideline discoloration.

that the rate of evaporation depends on a number of factors that cannot be controlled. The evaporation rate of a wet book is governed in part by the relative humidity and temperature of the ambient air, as well as by the porosity of the book's components: covering material, paperboard, and text paper. All of these factors can lead to unpredictable final results.

Natural Air-Drying The intuitive approach to drying a wet book is to stand it up on a table surface and fan open the leaves. Initially, this drying method appears to be the fastest, easiest, and least-expensive option. After all, the only items needed to get started are a table top, paper towels to absorb moisture, and electric fans for air circulation. In fact, the method is often not easy and can be more costly than other approaches, both in terms of labor and in need for future binding and treatment. A key issue in air-drying is that the approach is very labor intensive—there is a need for extensive checking, interleaving, rechecking, and reinterleaving.

Very wet books and very large books (ledgers, atlases, etc.) should not be fanned open, simply because the books are too bulky to stand on their own without tearing out of the cover. A book that is partially wet should be interleaved with absorbent towels or blotter paper to draw moisture from the leaves and from under the book. The absorbent materials should be replaced regularly, then removed when the book has dried to the point that the interleaving no longer picks up appreciable water. It is important not to interleave every page—this can result in permanent distortion of the binding. Evaporation acts more quickly if the air is dry and additional fans are used for air circulation. Books should be turned upside down regularly to even out the exposure of the edges against the tabletop.

Natural air-drying of books is often a race against the outbreak of mold. A rule of thumb is that you have about 48 hours before mold begins to bloom. The reduced humidity that dries the book also delays the mold bloom. If the air-conditioning system dehumidifies the air, reduce the temperature for drier air. Be cautious, however, because some cooling systems simply cool outside air without removing moisture; this can cause the humidity to increase dramatically. If the air is dry outside, typically in the winter months, open the windows. Bring in dehumidifiers; the small dehumidifiers used in homes will have

limited impact, but will help—be sure to empty them regularly.

Air-drying in this way generally yields the least-favorable results. The most common problems are cockling of pages and distortion of the bindings. To minimize these problems, close and put books under weight to press them as soon as they are dry enough. Books are ready to press when a moisture meter registers 6% to 8% moisture content. Be careful, because the covers may still be too wet to close and press.

Attempting to air-dry by fanning a book printed on coated stock paper is often futile. As stated earlier, coated pages “block” (adhere) together irretrievably as the water evaporates. In order for coated paper to dry successfully by evaporation, every wet page must be separated during the drying. This is usually only possible if the books are dried immediately after the initial wetting, and then only if the paper is partially wet or damp. The best approach is to freeze books with coated stock immediately, then freeze-dry them later.

Dehumidification Drying by dehumidification is most appropriate in situations where books are only slightly wet, partially wet, or damp. The idea is to introduce dry air into the storage space with the wet books while continually removing moist air. Commercial vendors who specialize in this service can accomplish this most efficiently by using desiccant dehumidification. Desiccant dehumidifiers, unlike typical home (refrigerant) dehumidifiers, force very dry air into a space (library stack, office, or room) and pump out moist air to speed the drying process. This is perhaps the most efficient procedure for drying wet books, especially when books can be dried on shelves without having to relocate or “pack out” the wet books.

Successful drying operations have been carried out based on this procedure without using commercial dehumidifiers, but conditions must be right. Home dehumidifiers alone will not reduce the humidity fast enough to prevent mold bloom. If the outside air is dry—below 35% relative humidity—as is often the case in winter, use fans to force in dry air, to circulate the air evenly throughout the space, and finally to force the humidified air out of the building. Dehumidifiers can be helpful in this operation, but again be sure they are continuously drained.

Throughout the dehumidification drying operation, thoroughly check the shelves.



Glossy (coated) paper “blocked” by wetting and drying cannot be separated without tearing.

Remove all books that, in your judgment, are too wet to dry closed on the shelf, so that they can be dried by another approach. Be sure that the dampest portion of each book is most exposed to the dry air by turning the fore edge out, or turning the book upside down on the shelf. A factor that aids the drying of books on the shelf is that the books are typically under pressure from adjacent books; this helps to keep the text and covers flat through the drying process.

Drying by dehumidification can have the best overall results of any drying technique. However, judgment is necessary to assess whether the extent of water damage may preclude this approach. A commercial vendor experienced in drying library material, or a library conservator or preservation professional, can help with decision making. Often dehumidification drying is combined with other drying procedures. Again, repeated checking of the materials, preferably by a conservator, is necessary to determine whether continued dehumidification will successfully dry the materials or if an alternate means of drying must be used owing to the type of material or the degree of wetness.

Thermal-Drying/Vacuum-Drying Attempting to hasten the drying of books by applying heat—whether by turning up the heat in the affected area, or by placing books either in a kitchen oven, a vacuum oven (vacuum thermal-drying), or in a microwave—should be strictly avoided. In all cases, further damage will result. Among the risks are increasing the possibility of mold bloom, and permanent physical damage from heat. A microwave oven will increase the temperature of water in a book to nearly the boiling point, causing irretrievable damage to the paper and cover. Vacuum-drying without application of heat has been used with partial success;

however, because of the complications and risks of this approach, vacuum freeze-drying is a better alternative.¹

Drying by Sublimation

Drying by sublimation, or freeze-drying, has come to be accepted as the least damaging and most successful technique for drying very wet books. It is clearly the best way to dry books with coated paper. To prevent “blocking,” it may help, in some cases, to rewet these books to ensure that they do not dry before they are frozen. Again, caution is advised; some surface coatings can begin to deteriorate from prolonged wetting—these papers should be frozen as soon as possible. A rule of thumb is that books should be frozen within six to eight hours of initial wetting.

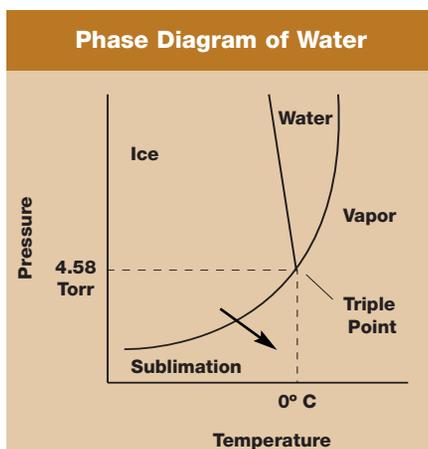
Freezing will stabilize the collection and arrest further damage such as bleeding, blocking, and distortion, even if the frozen books are not ultimately freeze-dried. Is it safe to freeze all books? In general, the answer is yes. Ice is less dense than water (ice floats), and consequently there is some expansion in moving from water to ice. The materials that make up books however, generally are not tightly compacted; the physical structure of the most common book materials—paper, paperboard, leather, vellum, wooden boards—includes enough space between fibers and cells that freezing alone will not cause damage. Blast-freezing is often recommended, in which the book’s temperature is rapidly reduced to below 18°C, thus quickly passing the temperature range of crystallization of water, so that smaller ice crystals form. However, such a procedure may not be essential. Circumstances will decide, but overall, the danger of wetting far outweighs that of damaging the book by freezing, even for the most valuable objects.

Vacuum Freeze-Drying Vacuum freeze-drying, a technique of mechanically controlled sublimation drying, has been shown to be an effective means of drying books in large-scale disasters. Because of the risk of overdrying and embrittling in

the vacuum chamber, unique and rare materials should be separated for drying by another technique.

During vacuum freeze-drying, the material is frozen, a vacuum is drawn, and energy (typically heat) is applied to the books, often through heated plates inserted between books, placed on heated shelves. As heat is transferred from the plates to the ice layer in the book, the ice crystals turn to vapor and escape. The process is monitored by measuring the internal temperature of the book; once the temperature rises above 0°C, the ice is gone. Another means of adding the “heat of sublimation” is through dielectrics (low-frequency radiowaves).

Typically in vacuum freeze-drying a second drying stage, called *desorption*—or evaporation drying—continues in a vacuum chamber after the book has reached 0°C. The temperature in the chamber can be as high as 30°–40°C or 85°–100° F. The reason for using a relatively high temperature target is to ensure that books in large-scale drying (many very wet books in a vacuum chamber) are dried to a point that avoids mold outbreaks.



This figure illustrates the physics of vacuum freeze-drying. The solid lines on the graph represent the boundaries between the three physical states of water: solid ice on the left, liquid water in the center, and gaseous vapor on the right. In physics, the triple point of water is the point at which water is in equilibrium and is stable in any of the three states. As illustrated by the diagram, ice in a vacuum below 4.58 torr and at 0°C or less cannot pass into the liquid state. However, ice in these conditions with the application of energy (often in the form of heat referred to as the “heat of sublimation”) will pass to the vapor state (see the arrow in the lower left).

The desorption period of vacuum freeze-drying can cause leather, parchment, and, in some cases, paper to lose excess moisture and flexibility and become brittle. Vacuum freeze-drying vendors thus allow a period of “reacclimation” for the book to reabsorb moisture from the atmosphere and return to a natural moisture content (approximately 8% relative humidity for paper). However, some permanent loss of flexibility can result from being overdried, especially for leather and parchment, which have a natural moisture content twice that of paper. Although overdrying can be controlled by stopping the drying process at a lower temperature (theoretically the book is dry at 1°C), this may not be practical in larger chambers or in larger drying operations.

Several steps should be taken to prepare materials for vacuum freeze-drying. First, separate books in boxes or crates with a single sheet of freezer paper folded around the book’s cover. It is not necessary to enclose the book—remember, the water vapor must have an avenue to escape from the book in drying. Second, as wet books are packed for freezing, take a moment to reshape and press flat each book; the book will come out of the freezer in the shape it was put into it. Third, to achieve the best results, sort materials by degree of wetness as they are packed. This is because the drying rates of individual books will vary according to the amount of water—hence, ice content—in each volume.

Freezer-Drying As noted earlier, sublimation occurs naturally in a freezer, especially in frost-free freezers. The most cautious approach in a water emergency is to freeze all the volumes that are suspected to be wet, and then to check volumes after they are frozen to decide on the appropriate drying method for each volume. Damp and partially wet volumes (see glossary, for definitions) may dry by sublimation in the freezer in a matter of days or weeks without further drying procedures. Even very wet volumes will eventually dry in a frost-free freezer over a period of months. Some flattening pressure should be placed on the materials to dry without distortion.

This “natural” sublimation is perhaps the most gentle means of drying very wet materials, and is the *best approach for rare materials*. Some vacuum freeze-drying vendors offer this type of freezer-drying. It is offered at a premium price because of the time it takes to complete (several

1. John A. Gibson and David Reay, “Drying Rare Books Soaked by Water: A Harwell Experiment,” *The Paper Conservator, Journal of the Institute of Paper Conservation* (Worcestershire, England), vol. 7 (1982): pp. 28–34.

INITIAL STEPS

The following is a checklist for responding to a water emergency. A professional conservator or preservation specialist can be invaluable in assisting with these steps.

1. Remove all standing water, reduce the temperature, reduce the relative humidity, and increase the air flow through the affected area as soon as possible.
2. Assess the extent of the damage and consider the appropriate drying techniques as discussed in this bulletin. Keep in mind that several approaches may be used in combination. Plan next steps according to the plans for drying.
3. Often water-damaged books are also damaged by dirt, mud, or mold. In general, cleaning should be deferred until after the material has been dried, to avoid smearing and driving soil permanently into paper or cloth.
4. If it is feasible to freeze all the affected books, do so; freezing is safe, it will stabilize the collection, and will not preclude future drying decisions.
5. If it is possible to identify materials that cannot be salvaged, do so as soon as possible, and concentrate efforts on materials that *can* be salvaged.
6. Always plan to freeze books printed on coated paper stock before they begin to dry, and before the coating begins to become soluble. Rewet books with coated stock if they begin to dry before freezing.
7. If materials are to be removed from the area, identify materials on the shelf by degree of wetness, as much as possible, before packing the sorted volumes. This will benefit later drying operations.
8. As materials are packed, separate items with a loose wrap of freezer paper, but do not enclose the items—moisture must be allowed to escape.
9. Gently close books and reshape them as they are boxed.
10. All wet books should be boxed or crated spine down, so that the volumes won't tear out of their covers.

months). Even leather and parchment can be successfully dried this way. A commercial freezer chest that has been modified to increase its efficiency for freeze-drying is now available to institutions for freeze-drying small quantities of wet materials over an extended period.

Natural Freeze-Drying In colder climates in winter, materials will dry by sublimation out of doors, or in an open, unheated building like a garage. Obviously, conditions must be appropriate to consider this approach—the temperature must remain below freezing, the relative humidity should be below 35%, and there should be good circulation of air. The materials should be kept under pressure to prevent distortion. To some, this approach may seem far-fetched, but a number of successful drying operations have been conducted in natural conditions conducive to sublimation. Security and monitoring of collections during drying must be planned if collections are dried outdoors.

CONTRACTING SERVICES

Semantics commonly causes confusion in recovery operations. There is no standardized terminology for the drying methods described in this bulletin in the disaster

- Write a letter of agreement to be signed both by you and the contractor that details the services to be provided, stipulates that frozen books are not to be allowed to thaw before drying, and states when the books are to be returned.
- Consult local and regional preservation service providers to locate vendors of recovery services. Regional library networks and local university libraries may have preservation offices that can provide referrals and advice. Conservators and preservation consultants may also be able to assist you in working with vendors.

COMPLETING THE RECOVERY

To complete the recovery, first be certain the books are dry. Books that have been dried in a freezer or air-dried can be checked with a moisture meter; consult a conservator or preservation consultant for assistance. Often a close tactile inspection is sufficient. Wet paper is cool to the touch—check in the gutter at the inside spine area of the book. Books that have been freeze-dried can be safely returned to the collection, assuming they are clean and in usable condition.

Soot and smoke odors represent a residual damage that is not only a nuisance but may continue to damage volumes. Smoke odor will eventually dissipate, but some basic cleaning measures may be used. First, vacuum the books, preferably using a vacuum cleaner fitted with a HEPA (high-efficiency particulate) filter. Second, natural rubber cleaning sponges can also be used to clean soot, dust, and mold from books. Third, there is anecdotal evidence that wrapping books in paper or enclosing books in boxes made with zeolite materials (used as chemical traps for gaseous pollutants) for a period of weeks has been effective in reducing smoke odor. Further, some desiccant materials (clays and silicates) may be safely used to absorb odors (check with a conservator or preservation consultant). A final word of caution is in order, however: The use of ozone generators, a typical commercial approach for reducing odors following a fire or flood, should be avoided. Ozone (O₃) is a highly reactive gas that can act as a bleach on books and paper. Moreover, the effects of ozone are long-term and may not be immediately apparent.

GLOSSARY The following is a quick reference to the drying terminology used in this bulletin.

Degrees of Wetness

Wet—A wet book is noticeably wet to the touch over at least 25% of the volume.

Partially wet—A book is partially wet when deformations (warping, swelling, cockling) are readily apparent in some part or over the entire book. Localized areas of the book (an edge, corner, or spine) may be obviously wet to the touch.

Damp—A damp book has absorbed moisture to the point that it is likely to grow mold at ambient temperatures. Deformations such as minor warping of covers or cockling of paper may have occurred, but not necessarily. Mold bloom on an apparently dry book is a dead giveaway that a book is humid.

Drying

Drying—Process of removing excess moisture from an object.

Moisture content—The total chemically bound and free water content of a material. Paper, leather, and cloth have a natural moisture content of 6%–16%. In drying, the goal is to remove excess moisture without reducing the natural moisture content of the material.

Evaporation-drying—Moisture escapes a material (paper, leather, cloth) as vapor from the wet state of water.

Sublimation-drying—Moisture escapes a material (paper, leather, cloth) as vapor from the solid (ice) state of water.

Techniques of Drying Books

Natural air-drying—Accelerated evaporation-drying based on increased air circulation (fans) and increased surface exposure of wet material (standing books open).

Dehumidification-drying—Accelerated evaporation-drying based on decreased ambient humidity and increased air circulation.

Thermal-drying—Accelerated evaporation-drying based on adding heat (examples include vacuum thermal-drying, oven-drying, and microwave-drying).

Note: Thermal-drying techniques are not recommended.

Vacuum freeze-drying—Accelerated sublimation-drying based on reduced air pressure (vacuum) in a freezer and the controlled application of energy (usually heat).

Freezer-drying—Sublimation-drying in a mechanical freezer; can be accelerated by frost-free cycling and air circulation.

Natural freeze-drying—Sublimation-drying in a cold and dry outdoor climate. Appropriate only in colder climates.

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CONSERVATION CENTER
for Art and Historic Artifacts
264 South 23rd Street
Philadelphia, PA 19103
215.545.0613
Fax 215.735.9313
E-mail ccaaha@ccaaha.org
Website www.ccaaha.org

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These general recommendations are intended to provide practical guidance in the recovery of water-damaged objects. The recommendations are intended as guidance only, and CCAHA does not assume responsibility or liability for any resulting treatment of water-damaged objects.