Preserving History: Subterranean Termite Prevention in

Colonial Williamsburg®

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Abstract:

Subterranean termites (*Reticulitermes* spp., *Coptotermes* spp. and *Heterotermes* spp.) are a significant challenge for the heritage sector due to a variety of factors, including termite adaptability, intricacies in period building design, the need to implement least-invasive control methods and limitations of product efficacy. Understanding termite biology, habits, movement patterns, and preferred food sources in relation to building construction elements is key to successful control. To aid in risk assessment, studies have been undertaken to determine the extent of damage a termite colony is able to exact on cellulous-rich material during a given time. Variations in size and species of colony, environmental conditions, and other factors make exact projections difficult; however, experimental results suggests that a colony of 200,000 can consume up to 12 pounds of cellulous per year. This makes subterranean termites one of the most significant threats to the preservation of historic structures in the United States. Developing an approach with IPM in mind significantly reduces the risk of damage to irreplaceable material and offers a holistic approach to termite prevention. Colonial Williamsburg has structured their termite prevention effort to include the prioritized categorization of 600 historical, reproduction, administrative, storage and museum structures by risk factor and preservation priority.

Keywords:

Subterranean termite; alate, dealate, swarmer, symbiotic protozoa, Integrated Pest management (IPM), termite baits, trench and rod, repellent termiticide, non-repellent termiticide

Image: history.org

Introduction

Image: Alex Wild

Though not considered an immediate risk to most museum collections, subterranean termites (*Reticulitermes* spp., *Coptotermes* spp. and *Heterotermes* spp.) are a pest of significance in the heritage sector. Colonies ranging from a few hundred termites to several hundred thousand can cause extensive damage to historic structures before evidence of infestation is noted. Control efforts are challenging due to a variety of factors, including termite adaptability, intricacies in building design, necessity of implementing least-invasive control methods and limitations of product efficacy. Colonial Williamsburg, the world's largest living history museum, uses a combination of in-house and contractual resources to minimize the likelihood of subterranean termite damage to over 600 buildings on property.

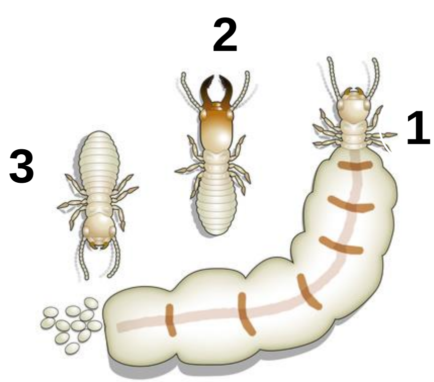
*The habits of Formosan termites (Coptotermes formosanus), a particularly aggressive subterranean species found in tropical climates and throughout the southern United States, are not addressed in this paper.

Biology and Behavior

Subterranean termites are eusocial insects that exhibit highly developed, cooperative behavior patterns similar to hymenopteran species. Colonies are divided into interdependent castes comprised of:

1. Reproductives
2. Soldiers
3. Workers

Each caste executes a separate but important task in the preservation of the colony.



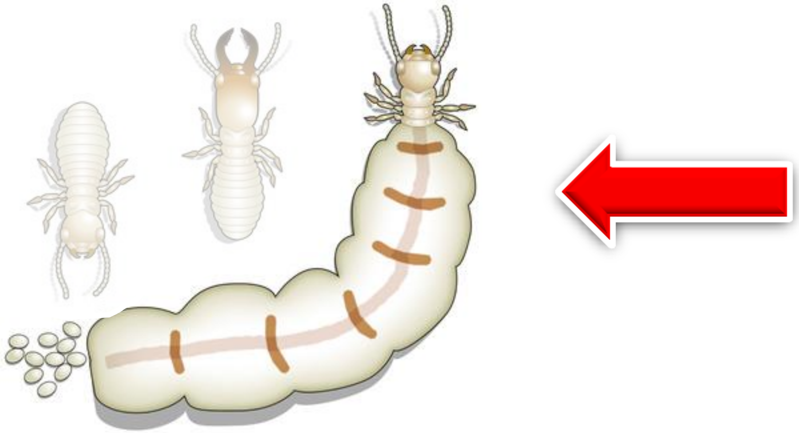
Alate reproductives:
kings and queens with wings

Dealate reproductives:
Kings and queens after wings have detached

Primary reproductives:
king and queen of the colony

Secondary reproductives:
Wingless supplements born after the colony is formed

1. Reproductives



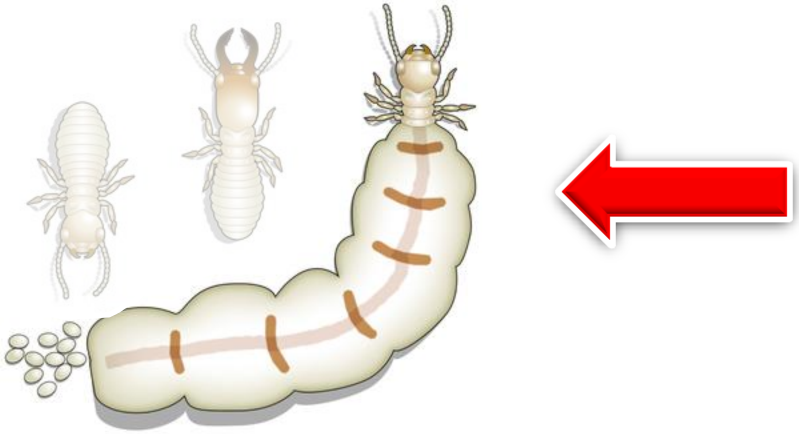
Reproductives (also called swarmers) make up a small percentage of the population, but are critical for colony expansion. Alates (winged kings and queens) are the only members of the colony typically seen by humans. Susceptibility to dehydration and predation limits their visibility to just a few hours or days during reproductive swarms.

As seen in the left margin, reproductives go through different stages of development. Mature kings and queens are responsible for expanding the colony population, with the queen directing most colony activities through pheromone communication.

Mature queens can lay up to 10,000 eggs per year.

Image:Jeff Weidhaas, Bruce Terminix, Bugwood.org

Termite swarms

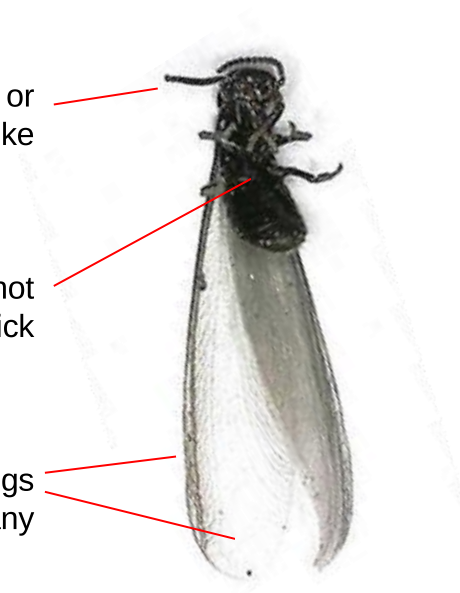


Most reproductive swarms occur in the early spring immediately following warm, wet weather. Alates are weak flyers that tend to be transplanted more by prevailing wind currents than by their own efforts. Soon after landing, new kings and queens shed their wings, thereby becoming dealates. After finding a mate, the pair seek shelter in an underground crevice or void to propagate and begin formation of a new, independent colony.

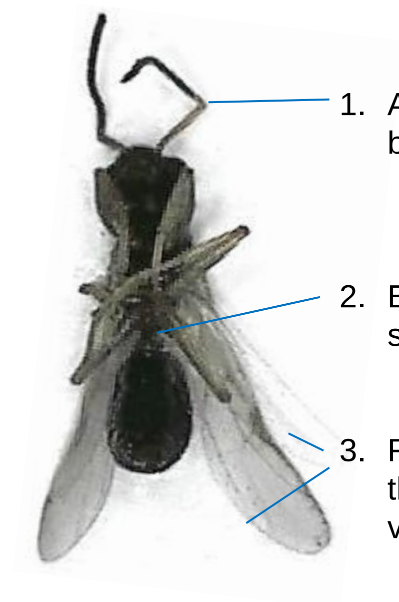
Because of similar appearance and swarming seasons, termite swarmers are sometimes confused with ant swarmers. The diagram on the next slide can help facilitate a positive ID. If termite swarmers are noted indoors, there is a good chance an infestation exists, and steps should be taken to identify and treat the afflicted areas.

Termite

1. Antennae straight or curved with beadlike segments
2. Middle part of body not segmented (thick waist)
3. Front/hind wings similar in size; many veins

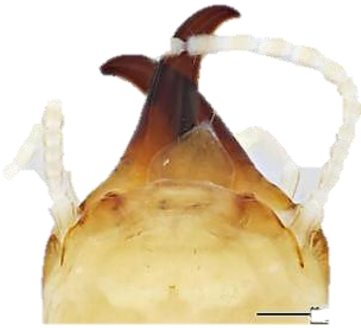


Ant



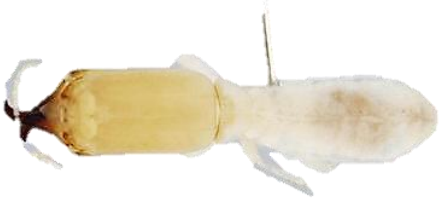
1. Antennae not beaded; bent/ elbow-shaped
2. Body has three distinct segments (thin waist)
3. Front wings longer than hind wings; few veins

Pest and Diseases Image Library, Bugwood.org



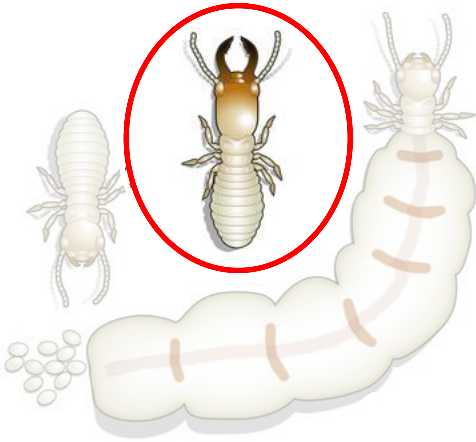
Large mandibles incurved approximately 70-90 degrees

Rectangular-shaped head; length 1.5 times width.



Pest and Diseases Image Library, Bugwood.org

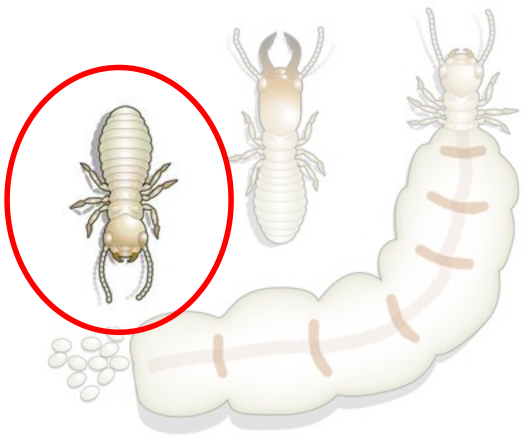
2. Soldiers



Soldiers are the protectors of the colony, typically representing 2-5% of the population. They can be distinguished from other termites by their oversized head and mandibles. Because of the dimensions of the head, soldier termites cannot forage or feed themselves, which makes them dependent on worker termites for feeding and care. Like workers, termite soldiers are completely blind.

When a termite shelter tube is disturbed, soldier termites tend to congregate around the opening to defend the nest against antagonists. The most common of these potential threats are foraging ants and termites from other colonies.

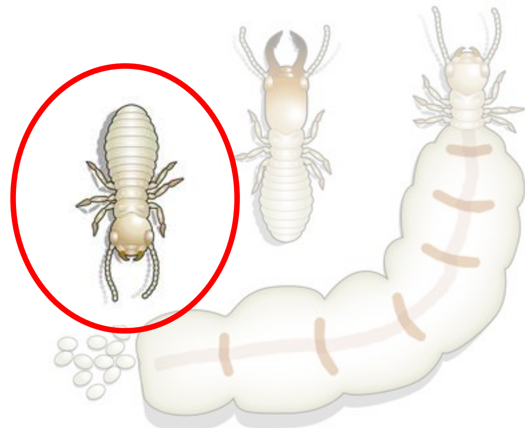
3. Workers



Workers are the largest class in the termite colony, comprising over 80% of the total population. Members of this caste are completely blind and work without sleep or rest. Because the queen survives much longer than the worker's life expectancy of 1-2 years, worker generations tend to overlap. Workers take care of all of the colony's basic needs, including:

- Tunneling and foraging
- Food retrieval
- Tending to the queen and her young
- Helping soldiers defend the nest

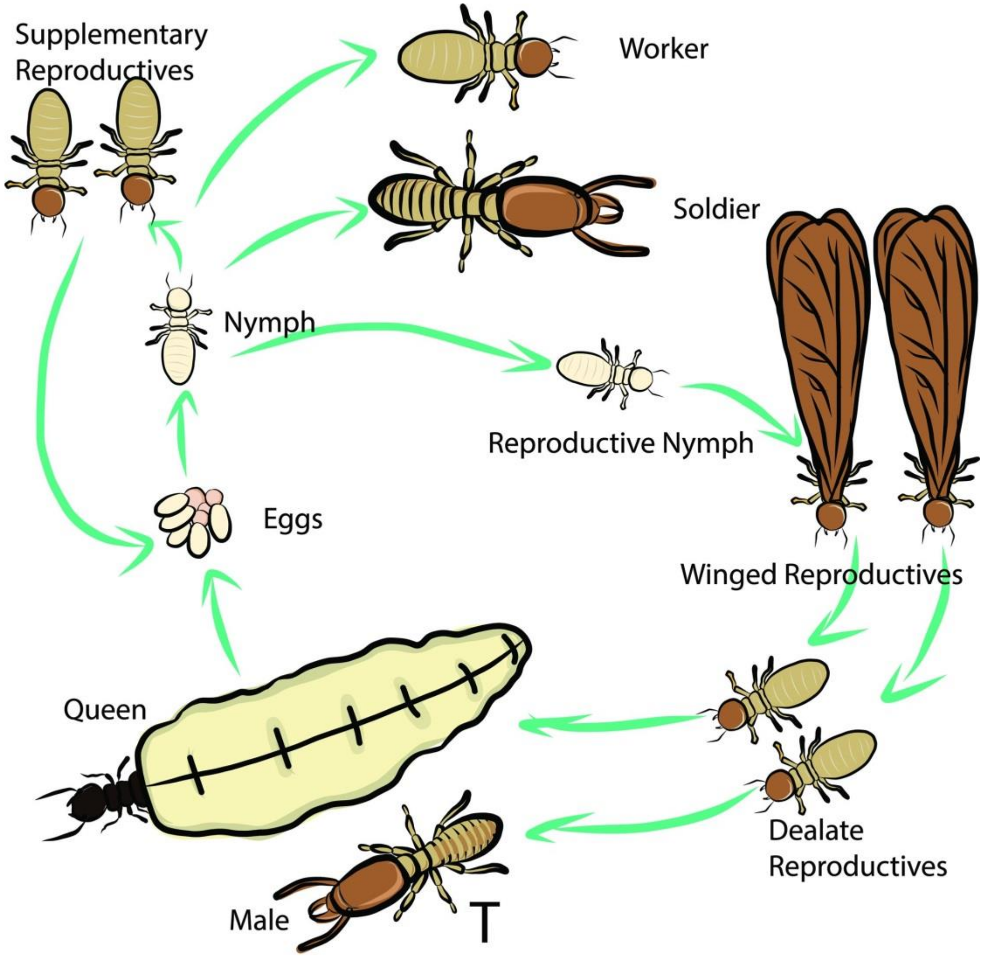
Image: Craig Bell



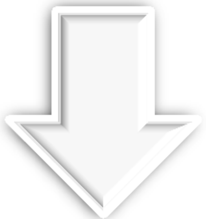
All structural damage, foraging, and construction of mud shelter tubes are perpetrated by the worker caste. Because of their significant role in sustaining the colony's needs, workers are the focus of most termiticides. Repellant termiticides are designed to thwart foraging efforts in the treated zone, while baits and non-repellant residual products are laced with slow-acting toxins which allow infected workers to spread the active ingredient throughout the colony by trophilaxis or touch before mortality sets in.

Because the workers are the sole source of sustenance for the colony, critical decimation of this caste usually leads to the collapse of the colony structure.

Subterranean Termite Life Cycle



Begin



Food preferences

Symbiotic protozoa living in the gut of worker termites enable digestion of cellulose, a typically indigestible organic compound found primarily in plant material. Since termites are not born with these intestinal microorganisms inside of them, they are passed from older termites to nymphs by way of trophilaxis (mouth to mouth transfer), and through other excrements. The protozoa, which can not subsist outside of the termite's gut, help reduce termite-ingested cellulose into a simple sugar, which the termite can then use as a sustainable nutrient. [1]

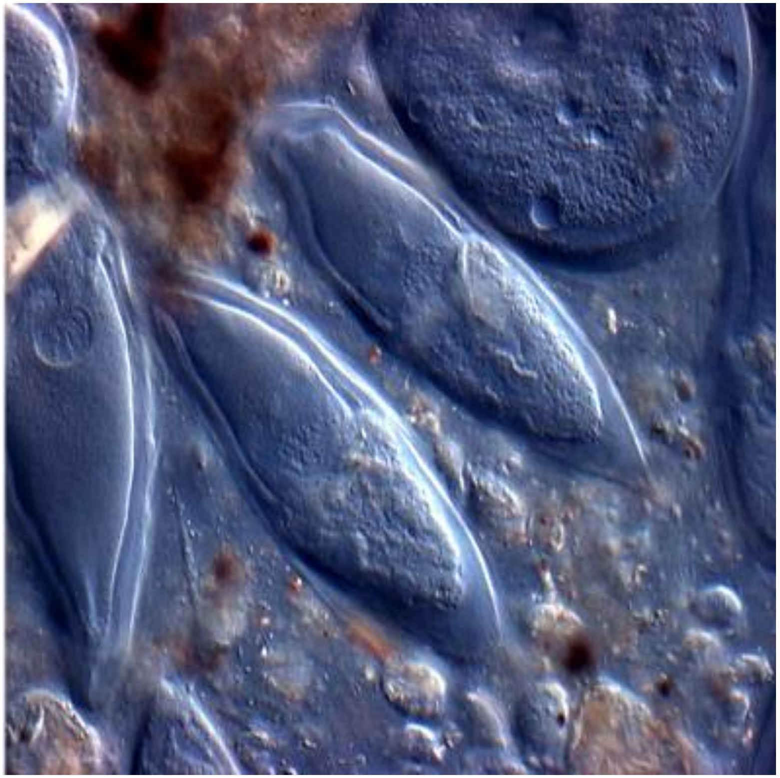


Image: NASA

The capacity to digest cellulose makes subterranean termite colony development an important part of the ecosystem. Tunnels excavated during foraging movements help to aerate the soil, while feeding activity accelerates the process of decay in lifeless, cellulose- rich material like fallen trees, logs and stumps. The resulting decomposition nourishes the soil and removes cumbersome build-up that would otherwise accumulate over time.

Unfortunately, subterranean termites cannot distinguish between fallen timber and the processed lumber used in the construction of homes and businesses. This makes them a pest of significance when their foraging patterns drift into areas of civilization – or vice versa. Each year, control and repair of termite damage (all species) is estimated to cost 15-20 billion dollars worldwide [2].

Image: http://www.ultimatetermitecontrol.com/termite-infestation-probability-map/

Movement in the Soil

Subterranean termites have thin cuticles and are unable to withstand conditions of low relative humidity. They spend most of their lives underground, moving primarily in the top 18 inches of soil during warm weather.[3] Field tests have shown that workers tend to prefer a soil moisture content of 10%-15%, and that they avoid exploration in soil that is too hot or cold.[4] Most energy is spent searching for new food sources, which involves systematic tunneling and foraging - preferably through pre-existing soil fissures. When a foreign object is encountered that leads above ground, termite workers build exploratory shelter tubes made of mud, saliva, fecal matter, and bits of wood to protect themselves from dry air and predators. If a viable food source is discovered, workers construct larger utility tunnels up from the ground, emitting pheromones inside to attract other workers to the food source.

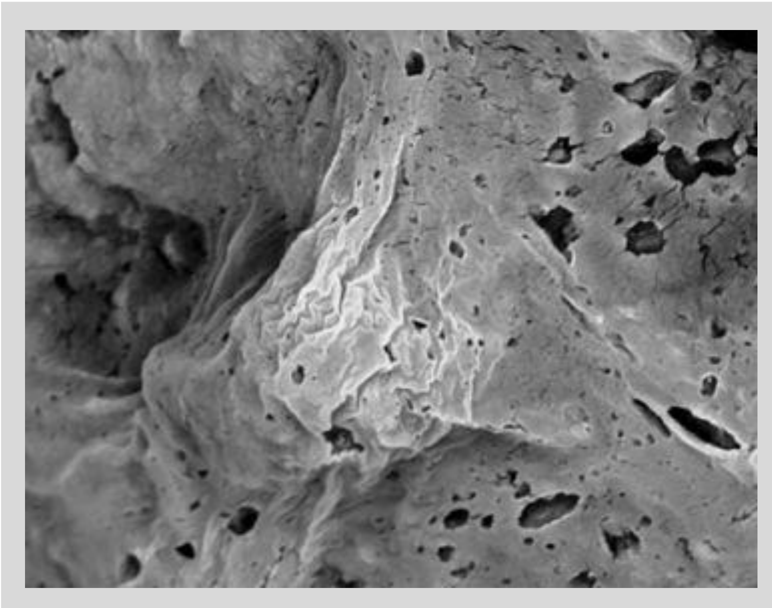


Image Citataion (left): Petr Ptáček, Jiří Brandštetr, František Šoukal and Tomáš Opravil (2013). Investigation of Subterranean Termites Nest Material Composition, Structure and Properties, Materials Science - Advanced Topics, Prof. Yitzhak Mastai (Ed.), ISBN: 978-953-51-1140-5, InTech, DOI: 10.5772/55145. Available from: http://www.intechopen.com/books/materials-science-advanced-topics/investigation-of-subterranean-termites-nest-material-composition-structure-and-properties

Pictured above is a photo of the outer surface of a termite shelter tunnel at x 7,000 magnification. The tube is rich in fecal material, which serves as a bonding element to seal in moisture and maintain elasticity. Relative humidity (RH) inside of the tube usually hovers between 80% and 90% to ensure the soft-bodied workers do not dehydrate, while RH in the actual nesting area may be as high as 100% 5.

Old, unused termite tubes are typically dry and brittle to the touch, while active tubes are more firm, moist, and darker in color.

Image (above): http://www.ctahr.hawaii.edu/termite/forthepublic/abouttermites/index.html

Utility tubes serve as highways between the termite colony and the food source, with foraging worker termites targeting the softer and more palatable springwood of the infested object. During colder weather, exposed tubes may be abandoned as termite colonies retreat below the frost line. If an infestation is situated in a protected area with favorable temperature and RH, feeding activity may continue uninterrupted for most of the year.

Both exploratory and utility tubes may be visible along the foundation and other areas of infested structures. They may also be completely hidden from view inside of structural voids. Because of this latter tendency, a subterranean termite infestation may go undetected for several years until the colony is well established and swarming reproductives appear.

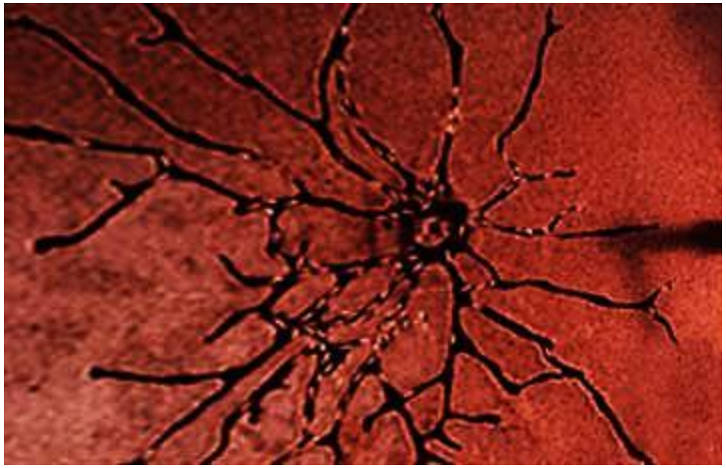
Image: Ryan Jones Colonial Williamsburg Foundation

Understanding the movements of subterranean termites in the soil is central to Colonial Williamsburg's termite prevention efforts. Dr. Barbara Thorne, an entomologist specializing in termite research at the University of Maryland, compared the expansion of a termite colony to that of a strawberry plant.

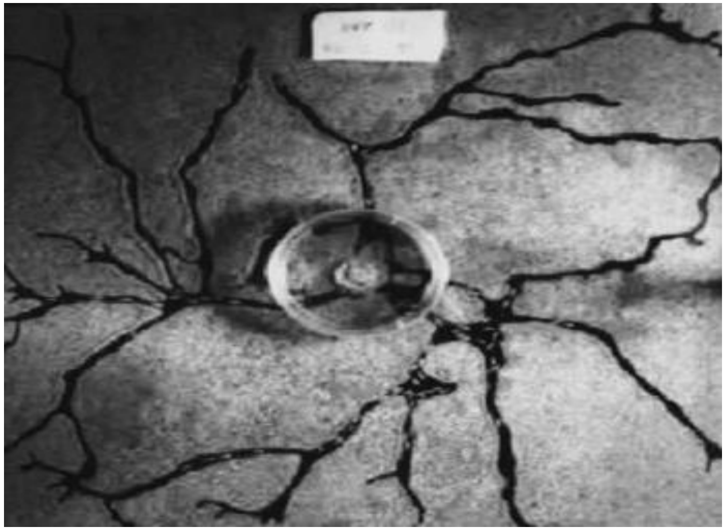
"A parent strawberry plant grows from a seed, as the termite colony begins with the king and queen. When the strawberry plant attains sufficient size and strength, it produces fruit. The tiny seeds on a strawberry are comparable to the alates (reproductives) produced seasonally by a mature termite colony. Strawberry plants make lots of seeds; termite colonies may produce loads of alates. These propagules are able to disperse far from their parent, but very few succeed in establishing a new plant or new termite colony.

In addition to seeds, strawberry plants can produce vegetatively through runners that trail from the parent and then root to initiate a new plant in the same neighborhood. Over time, the runner connection to the parent plant may be severed, and the budded plant functions as an independent unit. A satellite group of foragers in a subterranean termite colony is similar to a strawberry runner. It occupies a separate resource, but remains connected to the main colony by trails. Over time satellite groups may develop or acquire neotenic reproductives." [6]

An average property in the Mid-Atlantic region of the U.S. may contain scores of subterranean termite foraging trails similar to those depicted here. Once a colony is established, tunnels are launched outward in a pattern comparable to spokes on a bicycle wheel. [7] These trails are influenced by surrounding soil conditions, but not all of them lead to a viable food source. When a good food prospect is discovered, unfruitful tunnels are closed off and pheromones are deposited in the active tunnel to recruit more termites to the feeding site. If the food source is large enough, the foraging termites may eventually congregate to form a sub colony, with the cycle repeating as long as food sources are plentiful.



Images: http://polymer.bu.edu/ogaf/html/chp52act1.htm



According to a study conducted in central North Carolina, there may be 12-36 termite colonies at different stages of development on a given half-acre swath of property in the Mid-Atlantic region.[8] Foraging paths are influenced by:

1. Elevated soil moisture
2. Temperature/shade (preferred soil temperatures ~ 70F)
3. Poor drainage
4. Root systems, drainage lines and other physical guidelines 2
5. CO_2 emissions from stumps and other wood debris in the soil

These factors can work independently or in concert to lure satellite colonies into the vicinity of man-made structures. Old tree stumps in close proximity to the building provide a viable food source and a possible root path to either structural utility penetrations (like water or sewer) or to the foundation itself. Seemingly inconsequential deficiencies like leaky outdoor spigots, condensation dripping from AC units, or poorly maintained gutters that overflow during heavy rains can become a catalyst for termite infestation if not addressed. Heavy mulch beds situated directly against foundational elements tend to raise the soil moisture level by preventing evaporation of rain water, inviting termite exploration of the area. If the soil happens to also be rich in decaying cellulose, the likelihood of satellite colonies being established a few feet from the foundation is high.

Also high on the list of potential outdoor attractants are woodpiles and other cellulose–rich debris. When these are stored directly against a structure for long periods of time without proper rotation of wood, the likelihood of infestation is increased. Though termites cannot sense the actual cellulose content of the wood from their below-ground vantage point, they can be attracted by any one or more of the following:

1. Shade created by the resting wood prevents evaporation, which raises the moisture content of the soil and mitigates temperature extremes into a milder and more suitable foraging range.

2. Uncovered wood acts as a sponge for precipitation, further contributing to elevated moisture levels and fungal growth

3. As with stumps, aged firewood releases CO2 vapors during decay. These vapors were shown in a controlled study to be attractive to foraging termites

Images: Ryan Jones; Colonial Williamsburg Foundation

Infestation

Once attractive soil conditions succeed in luring termites close to a structure, there is a good chance that foraging workers will eventually bump into foundational elements of the building. Deficiencies in the substructure may then be investigated and exploited for easy access to wooden joists and other cellulose-rich material sitting directly on top of the foundation. In this image, the crack in the foundation of the porch crawl space provides ideal conditions for termite foragers to build shelter tubes that will lead directly into the moisture-damaged wood located above. Numerous studies have shown that termites prefer feeding in moisture-rich, fungus-infected wood, making this deficiency a perfect prospect. Studies also suggest that wood moisture content above 30% can support an aerial infestation indefinitely that has no contact with the ground. [9] From a human's perspective, none of the termite foraging activity in this location would likely be visible from the outside of the structure, leaving termites uninhibited to carry on their consumption of the wood until the colony reached a high level of maturity and alates were noted during a swarm.


Image: Ryan Jones; Colonial Williamsburg Foundation

After initial penetration, workers often follow foraging patterns similar to those demonstrated in their below-ground habitat by building shelter tubes along structural guideposts. Areas like corners, mortar joints, and cracks between wooden beams should be carefully examined during preventative inspections to ensure that infestations do not go unnoticed. Old tubes should be notched or completely removed to establish a baseline for monitoring activity.

Images: Ryan Jones; Colonial Williamsburg Foundation

Unfortunately, not all termite activity is readily discernible from the surface. Once a food source is established, workers may excavate galleries just below top layer of infested wood, making the possibility of undetected penetration through crevices in block foundations and subsequent wood consumption in sill plates and wall-void studs very real – even in the midst of competent inspections.

To allow for this, experienced termite inspectors supplement visual examinations by physically tapping a screwdriver, pick or other blunt object against the wood to test for soundness. Hollow-sounding thuds are investigated for activity. Moisture meters and other electronic devices can be utilized to hone in on areas of concern, and, though costly, digital sound and thermal detection devices can help confirm unseen activity. In addition, termite-detecting dogs are becoming more accepted in the industry as an option for pinpointing infestations.

Top and bottom: *Hidden damage may lurk under the seemingly sound surface of infested wood and compromise the structural stability of the timber.*

Images: Ryan Jones; Colonial Williamsburg Foundation

Occasionally, subterranean termites may excavate tunnels close enough to the surface of an infested structure to break through the final layer of paint, wallpaper, or other material. These breaches are repaired by worker termites with mud and are a clear sign of activity; therefore, walls and ceilings should not escape scrutiny during inspections.

Images: Ryan Jones; Colonial Williamsburg Foundation

Predicting the damage potential of an average subterranean termite colony

Diverse efforts have been undertaken to predict the damage potential of subterranean termite colonies. A number of variables, including geographic location, moisture levels, seasonal nuances, available food sources, wood type, colony vigor, and presence of natural predators can affect accuracy of projections.

Image: USDA Forest Service Archive, USDA Forest Service, Bugwood.org

Studies conducted by Barbara Thorne using six species of Reticulitermes suggest a daily consumption rate in the range of 0.015mg - 0.2mg per termite, with a mean of about 0.08mg per termite per day. [10]

If an average colony size of 200,000 is factored into this estimate, and the assumption is made that the colony is not significantly swayed by one of the previously mentioned variables, a projection of 12.9 pounds of damage potential per colony per annum (1.07 pounds per month), or approximately 10 linear feet of a pine 2x4 can be made. If the colony were significantly smaller in size (in the 60,000 range), the damage would be reduced to 3.8 pounds of wood per year – approximately 3 linear feet of a pine 2X4.*

**The purpose of this projection is to an help readers gain a visual perspective of the progressive damage a subterranean termite colony is capable of perpetrating under stable conditions. Estimates should not be seen as an attempt to define the behavior or feeding habits of subterranean termites under any and all circumstances. Each real-life scenario is unique and will present its own peculiarities.*

Image: Scott Bauer, USDA Agricultural Research Service, Bugwood.org

Obviously, these estimates have a broad margin of error, as termites are known to obtain nourishment from multiple food sources at once. Foraging workers feeding in a zone with attractive conditions tend to honeycomb through the soft grain of the lumber, making complete dissolution of any one piece of wood unlikely. Nevertheless, the projections can serve as a starting point in determining the rate at which building materials inside a historic structure are at risk of being compromised, and, more importantly, how long a colony must be rooted to cause significant damage.

Image (right): Dani Jaworski; Colonial Williamsburg Foundation

Time lapse of infestation	Estimated wood consumption
2 years	25.8 lbs. / 20 linear feet of pine 2x4
4 years	51.6 lbs. / 40 linear feet of pine 2x4
6 years	77.4 lbs. / 60 linear feet of pine 2x4
8 years	103.2 lbs. / 81 linear feet of pine 2X4
10 years	129 lbs. / 101 linear feet of pine 2x4

Represented in this chart is the projected damage from a mature subterranean termite colony over a ten-year period. For simplicity, the area of infestation is condensed into a simulated ten-foot linear wall built with 11 studs (16" centers and doubled on the ends), two top plates, and a bottom plate for a total of 7174 cubic inches of wood. Under these circumstances, an established termite colony would undermine the load-bearing capacity of the wall by fifty-percent in approximately five years. If the progression of the termite colony were left unchecked, the load-bearing capacity of the studs would likely fail sometime over the next few years, causing a bulge or sag in the wall, or, worse yet, a partial collapse during unusual or adverse environmental conditions.

While forecasts such as these may be unsettling, they underscore the improbability of catastrophic damage occurring as a result of a single, isolated oversight during an inspection. Instead, serious termite damage is more often the result of prolonged lapses in competent inspection coupled with partial or complete failure of preventative treatment measures. The reasons for these failures are varied. Some are caused by overconfidence in a preventative treatment that was not applied correctly or maintained as necessary for the desired level of performance to occur. Others happen when the treatment measures cannot override the severity of conducive conditions. Optimistically, a base knowledge of the cumulative, slow-moving damage cycle caused by subterranean termites counters the notion that action must be taken within a few hours or days of discovering fresh subterranean termite tubes. Significant damage does not occur in increments of days or weeks, but gradually over the course of months and years. Once activity is confirmed, there is usually time for prudent consideration of treatment options before action is required.

Image: Alex Wild

The termite control industry from a consumer's perspective

Because of the complications involved in termite control, many home and business owners have come to view termite protection with the same mindset they would an insurance policy, with the contractual obligations having two diametrically opposed focal points:

1. An initial treatment and/or maintenance program to prevent termite infestation
2. A guarantee of repairs/retreats if the protection system fails

Unfortunately, the end-result of this transaction is not always a termite-free building. Instead, a consumer may find him or herself purchasing a "feeling of security" that stems from assurances of repairs or retreats if the termite treatment fails. To be fair, the majority of licensed termite contractors are honest and render a reasonable effort to prevent infestation. In some instances, however, persuasive termite marketing can be an illusion. In the interest of boosting revenue, a less-conscientious contactor may offer too-good-to-be-true discounted services in hopes of accumulating a high volume of clients, and be willing to concede a certain amount of damage as a routine cost of doing business. Inexperienced employees may be put in the field too early because of rigorous route demands, and/or supervision may be inadequate. Over time, these types of administrative problems may result in oversights, poor service, and termite infestations. Though all legitimate termite services are connected to a high volume of liability insurance, repeated claims against this policy can drive the contractor's insurance rates up or lead to cancelation. In the face of multiple damage claims, a less reputable contractor may attempt to exploit ambiguities in contract wording to mitigate losses and avoid penalties. For example, many termite contracts stipulate near-perfect moisture and/or structural conditions before structural repair guarantees are honored, making the consumer a certain candidate for disqualification. The exact timing of a termite infestation is also difficult to prove, making accountability for inactive damage uncovered after the initial treatment problematic. These issues are all-too-often glossed over during negotiations or buried in the fine print of the termite prevention contract. When discussing a termite agreement, it is imperative that clear expectations be established and understood by all parties to preserve a good working relationship after the initial treatment has taken place. (see tips for choosing a contractor)

Choosing a contractor

History teaches that there is little merit in choosing a termite contractor based solely on size or notoriety. No matter the circumstances, nearly all pest control operations are divvied into individual routes, which are serviced by technicians who work most of the day without direct supervision. A contractor may have a well-established brand, effective marketing strategies, and a charismatic sales team, but the success or failure of the effort depends largely on the diligence of the service technician. If he or she is conscientious, honest and well-compensated, there will not likely be problems. If there are shortcomings in any of these areas, a client's trust and confidence may not be warranted. In 1996, one of the industry's leading termite contractors settled in a 7.7 million dollar lawsuit involving the purported misapplication of termiticide around some 7,000 homes. A close competitor, also of national prominence, was ordered to retreat nearly 20,000 homes that were allegedly not safeguarded according to the terms of the service agreement.[12] If these claims are accurate, there were obvious internal issues that went above and beyond the incompetence of an errant technician. The sheer volume of the contended incidents are a reminder that system failures can and do occur. No doubt the consumers in these instances thought they were well-protected against infestation after their initial service, but were unpleasantly surprised when swarmers continued to appear year after year or heavy damage was exposed during unrelated renovations. To add to their grievances, many clients get caught up in in lengthy arbitration or legal proceedings in order to collect the money spent repairing damage.

In a best case scenario involving a damage claim, the contractor and the consumer will have already established clear expectations for liability. This will enable key players to work together to repair damage, treat the source of the infestation, and identify the reason for system failure. In many instances of damage to commercial or residential structures, even competent repairs can decrease the property value because of stigmas in public perception associated with termite infestation. In reality, if the repairs were well-executed, the value of the building would not be diminished because the building materials have no significance beyond their intended purpose of providing structural stability.

This mindset, though applicable in the residential and commercial market, is not acceptable in a heritage environment. Once WDI damage has occurred in a historic structure, the value of the property is irreversibly compromised. Repairs and retreatments may reestablish structural stability and ward off future infestations, but the damage to historically significant structural elements cannot be undone. Thus, the methodology of any termite program in a historic house must be the results-driven prevention of damage rather than a feeling of security based on assurances of repairs and retreats if a system fails. This is best accomplished using a multi-dimensional approach rooted in the principles of IPM.


Image: history.org

A key element in negotiating this standard with outside contractors is to ensure that the appropriate institutional points of contact, be they collections managers, contract administrators, or in-house IPM staff, have been versed in the basics of termite behavior, biology, control options, and trending research. A person need not be an expert in termite management to accomplish this, but sufficient comprehension of subterranean termite fundamentals should exist to empower staff to play an active role in managing termite treatment and prevention strategies. Most state extensions or regulatory agencies offer fact sheets, courses and other resources to help educate consumers who are choosing a termite contractor.

In the meantime, staff should be committed to working diligently in the removal of incorrect cultural, structural, storage and sanitation practices that could lead to termite infestation. Though this will likely turn out to be an imperfect and progressive task, it will put the contractor in a better position to succeed in carrying out whatever preventative measures have been agreed upon in the service contract.

Image: history.org

MuseumPests.net

A Product of the Integrated Pest Management Working Group

TIPS FOR HIRING A PEST MANAGEMENT PROFESSIONAL (PMP):

1. Get bids from several different contractors to make sure you have a good feel for the pricing and service options available in your area.

2. Make sure the contractor you select is reputable and can provide proof of licensing and insurance. Check to see if the contractor is a member of the NPMA (National Pest Management Association) or other groups that promote good IPM practices.

3. Make sure the contractor is well-trained and committed to practicing the principles of IPM. Ask about credentials, training, or references regarding prior experience in a museum setting. Ensure that the contractor is familiar with pest concerns specific to museums and collections, as the pest pressures in a museum setting are much different that those typically dealt with on a typical pest management route.

4. Make sure you have been introduced to the technician who will be servicing the museum. If it is feasible, request that only one technician be assigned to your building(s). Ask about what arrangements will be made to ensure continuity if the technician designated to your museum decides to seek other employment.

5. Request that regular meetings take place between the pest contractor and key museum personnel to ensure the IPM program is functioning as it should.

6. Make sure the contractor understands the process of communication that should occur before applying pesticides in the building. Discuss which treatments will be provided by in-house museum personal (such as freezing, anoxic, etc.) and which treatments will be provided by the pest contractor.

7. Make sure the contractor has an acceptable response time in the event of a pest emergency.

8. Make sure the contractor understands museum security procedures that may create a need for special scheduling (such as requiring the contractor to have an escort while servicing sensitive areas of the museum).

9. Make sure your institution has offered the pest contractor adequate training in public safety, object handling, maintaining aesthetics when placing traps, and other areas of concern before the initial pest service is carried out on the building.

10. Discuss tactics for monitoring and reporting to ensure that high risk and sensitive areas in the museum are being properly addressed.

11. Remember that the pest contractor will be an integral part of your overall conservation program, and that you will be working closely with him/her to ensure that your collections are protected from pests. You should be comfortable with the personality, attitude, and overall disposition of the technician and his/her supervisors. You should also be prepared to involve yourself in the dynamics of the program on a long-term basis. Establishing a good working relationship with your pest contractor will be a key element in establishing IPM in your institution

Colonial Williamsburg’s Restructured Prevention effort

In seeking to preserve over 600 structures on property, Colonial Williamsburg utilizes a system of proactive checkpoints to minimize the risk of subterranean termite infestation.

Careful inspection is the key to any successful IPM effort, and should be the first layer of defense in termite prevention. Colonial Williamsburg conducts annual in-house assessments of each building on property, which take into account the following fluctuations:

- Prevailing environmental conditions
- Site history of termite activity
- Mechanical, physical and cultural conducive conditions
- Historical value of structure

As a peripheral advantage, inspections conducted by in-house IPM staff facilitate an extra set of eyes on the environmental control efforts in historic buildings. Collaboration between conservation technicians and the IPM specialist encourage synergistic practices that are more likely to detect environmental glitches before they progress into full-blown complications.

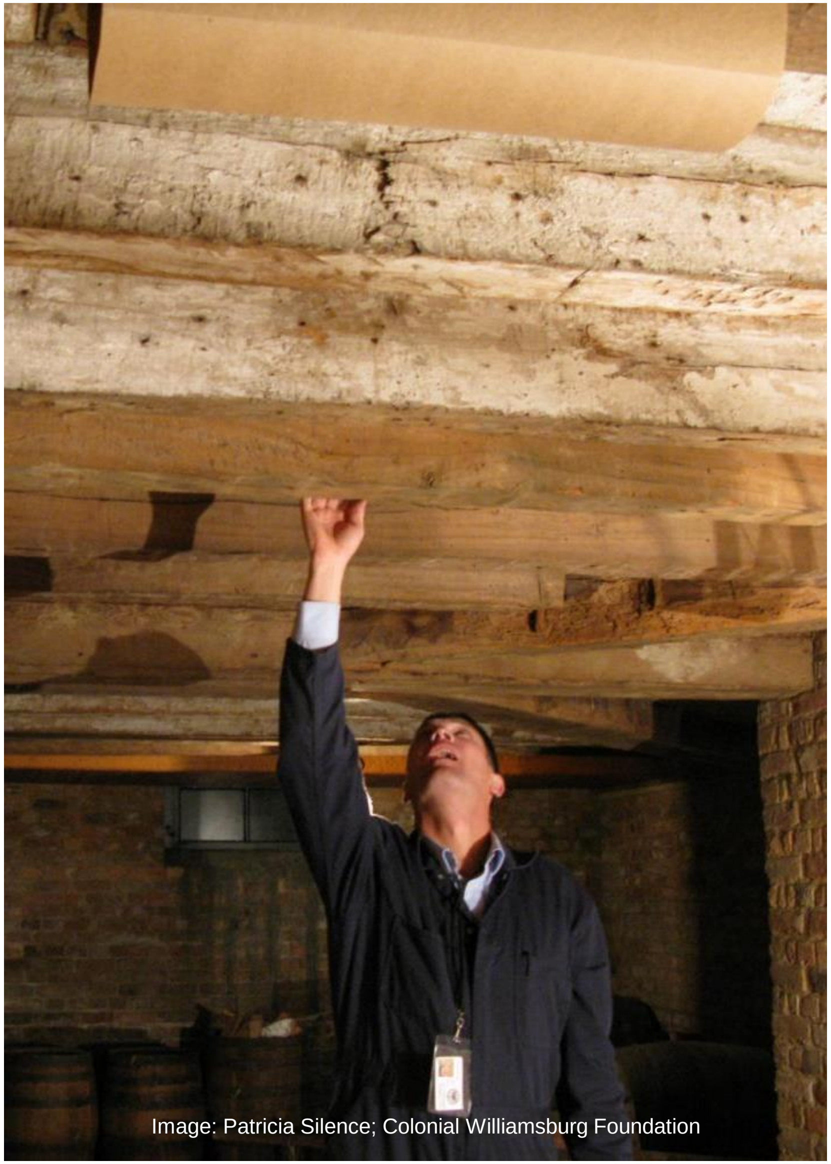
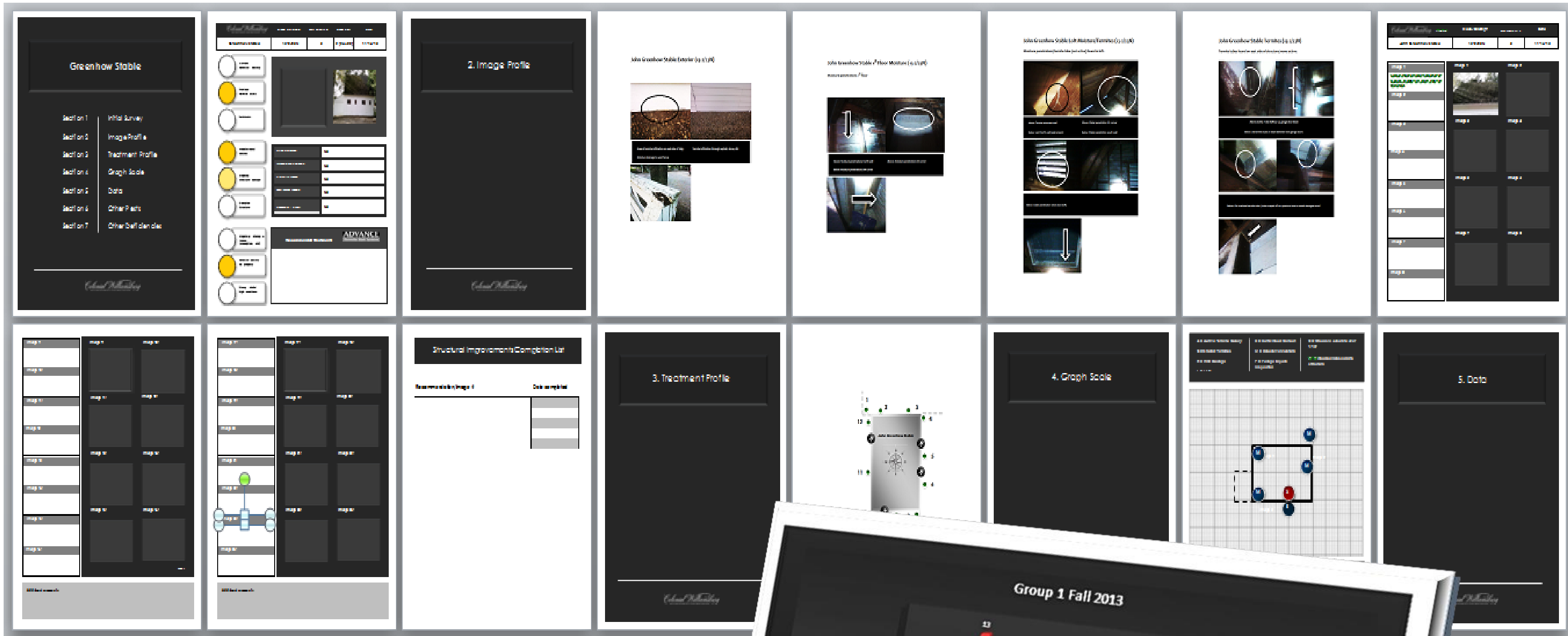
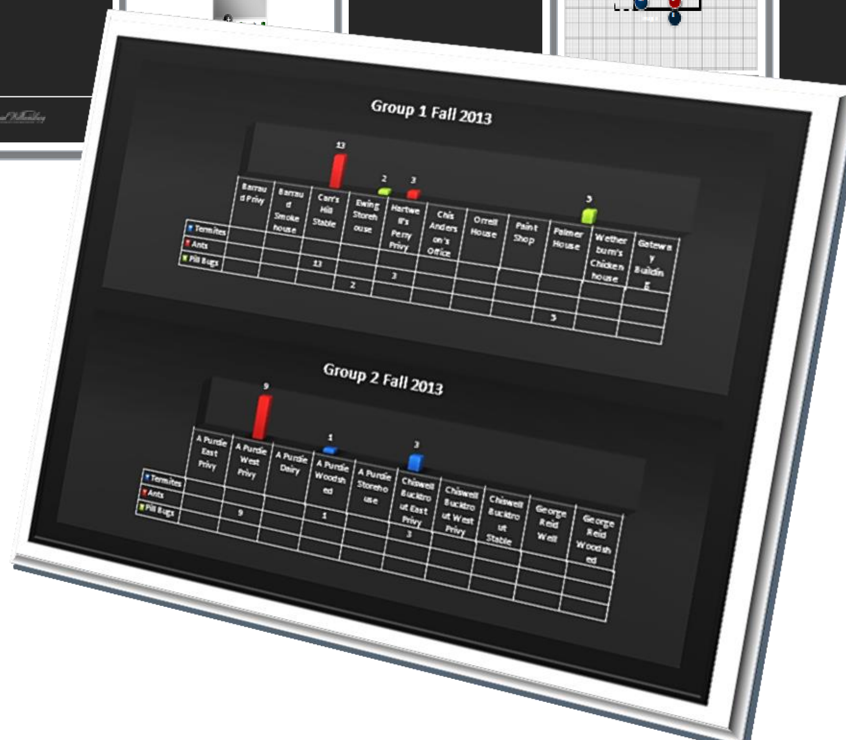


Image: Patricia Silence; Colonial Williamsburg Foundation





As part of this process, a photographic record of each building is kept on file, with each site being categorized into a three-tiered priority-rating system using the conditions noted during the inspection. Conservation technicians are given access to these notes, allowing heightened awareness of problematic structures. The criterion for each treatment cycle is as follows:

Tier 3 — Low risk of infestation

Tier 2 — Moderate risk of infestation

Tier 1 — High risk of infestation

Image: Colonial Williamsburg Foundation

Examples of Tier 3 Qualifications ***(low risk):***

1. Easily inspected buildings with simple design and no history of termite activity

2. Maintenance support buildings built primarily with concrete and steel

3. Buildings with environmental conditions that limit the likelihood of termite attraction

Schedule:

No pesticides used

Preventative maintenance on Tier 3 structures consists of a yearly inspection of the exterior/interior, with no preventative termiticide application required. Buildings in this group are inspected to the fullest extent possible, including basements, crawl spaces, and attic voids. If no changes are noted when inspection notes are compared with those of the previous year, and no conditions are observed that arouse suspicion of activity, further action is unnecessary. If conducive conditions are found on property, communication is made to in-house maintenance staff who implement cultural, mechanical, or physical improvements to lessen the likelihood of infestation.

Successful execution of such a large-scale effort hinges on excellent communication and follow-up between in-house IPM staff, maintenance departments, and contracted termite prevention specialists. This approach, though time-consuming, has the potential to significantly reduce the amount of preventative termiticide applications being carried out on property.

Above: *Colonial Williamsburg maintenance staff respond to work orders for building improvements at a historic outbuilding. These tasks include priming and painting, patching, leak repair, physical exclusion, landscaping modifications, and other preventative measures that will ultimately decrease the likelihood of infestation by termites and other pests.*

Tier 1 — Low risk of infestation

Tier 2 — Moderate risk of infestation

Tier 3 — High risk of infestation

Image: Colonial Williamsburg Foundation

Examples of Tier 2 qualifications ***(Moderate Risk):***

1. Reproduction or office/support buildings with a limited history of termite activity

2. Buildings too complex for visual inspection as a stand-alone method of prevention

3. Buildings exhibiting conducive conditions that cannot be permanently resolved with reasonable maintenance improvements.

Schedule:

- *Yearly inspection*

- *In-ground baiting/monitoring system installed/ maintained around perimeter of structure*

Advantages of using baits	Disadvantages of using baits
Environmentally friendly	Efficacy difficult to gauge
Targeted applications	Slower colony reduction Possibility of termites not feeding in stations

Above: *In-ground subterranean termite bait stations like the one pictured above utilize trophilaxis (a process where food is shared among members of the colony) to distribute termiticide throughout the colony.*

Image: BASF

Termite bait systems

To begin the monitoring process around a Tier 2 designated structure, a series of hollow eight-inch plastic termite stations are prebaited with cellulose-rich feeding materials and placed at ten-foot intervals 1-2 feet back from the foundation.

The stations have vertical openings in the shaft that allow termites to investigate and feed on bait reservoirs inside.

Image: BASF

Image: Ryan Jones Colonial Williamsburg Foundation

Stations are inspected 1-4 times per year, depending on the product being used and the frequency of activity in the stations. Despite claims by some to the contrary, the subterranean termite bait matrixes do not proactively attract foragers in the vicinity. [13] Instead, perimeter placements serve as a series of stumble traps that monitor the soil for colonies making their way closer to the building. At best, perimeter stations are a hit-and-miss prevention strategy, and caution should be exercised when giving consideration to their use as a stand-alone method of treatment. Essential to efficacy are detailed site inspections, structural, sanitation and storage improvements, regular analysis of station inspection data, and installation of additional termite stations in foraging-prone areas. Research shows that the closer the termite station is installed to active foraging trails, the more likely it is to serve its purpose.[14] Such areas in Colonial Williamsburg include:

- Wooden fence posts abutting building structures
- Stumps that cannot immediately be removed by landscaping staff
- Areas of soil next to woodpiles
- Soil underneath wooden door stoops
- Soil near wood/ground contact that cannot immediately be remedied by structural or landscape modifications

Images: Ryan Jones Colonial Williamsburg Foundation





As with other outdoor areas, activity in bait stations is heavily influenced by the surrounding soil temperature and moisture content.

Studies conducted at Clemson University suggest that termite bait stations installed in open, unshaded areas were most active during the spring and fall, as the extremes of heat and cold of the summer and winter months rendered ground temperatures inhospitable for foraging.

Stations placed in protected or shaded areas proved to be more active during the summer, where soil temperatures hovered between 71.6F-75.2F. [15]

Having a good feel for the environmental conditions present on a given property will prove valuable to overall station placement and efficacy.

Image: Ryan Jones Colonial Williamsburg Foundation

Colonial Williamsburg utilizes a specially designed termite station that is prebaited with a non-toxic, highly palatable cellulose-rich substance. The bait reservoir is divided into two parts: a soft-wood spiral on the bottom (1) and a compact bait cartridge on the top (2). When termite feeding activity is noted, the top monitoring cartridge is replaced with an active bait matrix (3). The split-level arrangement of the bait components prevent disturbances to the forging termite colony that might serve to drive them away while the monitoring cartridge is being replaced .

Images: BASF

Active bait cartridge

3

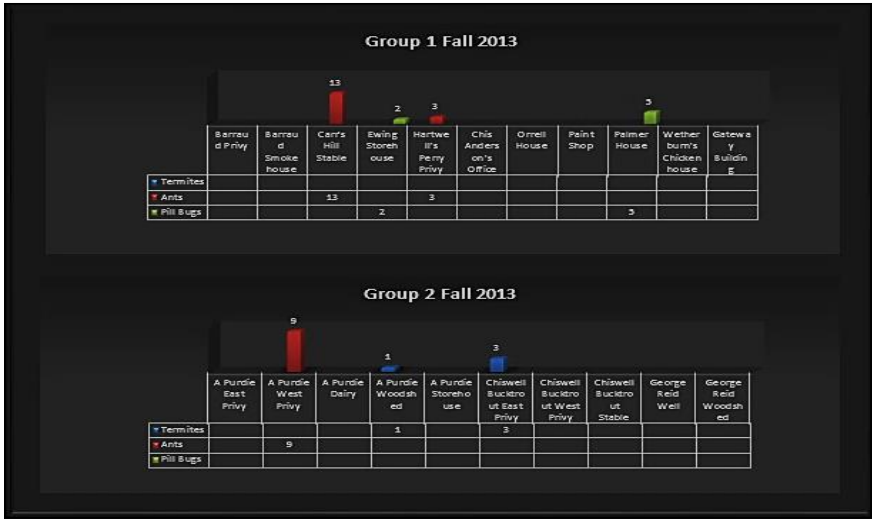
Foraging termites are not disturbed in the bottom chamber (1) while the bait matrix on top (2) is inspected and serviced.

Non-poisonous, high cellulose bait cartridge

Soft wood matrix

Gradual reduction in population occurs when Diflubenzuron, an insect growth regulator (IGR) in the bait cartridge, is consumed and then dispersed throughout the colony by foraging workers. Like some other established IGR's, Diflubenzuron disrupts the production of chitin, a carbohydrate used to form the termite's exoskeleton. These chitin inhibitors work exclusively on immature worker stages, making the process of colony reduction lengthy. Such a course of action can take anywhere from a few weeks to a year or more, depending on the size of the colony and other prevailing conditions.

Though Chitin inhibitors seem to be the most popular choice of active ingredient, there are others on the market that claim to produce good results.



Group 1 Fall 2013

	Barraud Privy	Barraud Smoke house	Carr's Hill Stable	Ewing Storehouse	Hartwell's Perry Privy	Chis Anderson's Office	Orrell House	Paint Shop	Palmer House	Wetherburn's Chicken house	Gateway Building
Termites											
Ants			13		3						
Pill Bugs				2					5		

Group 2 Fall 2013

	A Purdie East Privy	A Purdie West Privy	A Purdie Dairy	A Purdie Woodshed	A Purdie Storehouse	Chiswell Bucktrout East Privy	Chiswell Bucktrout West Privy	Chiswell Bucktrout Stable	George Reid Well	George Reid Woodshed
Termites				1		3				
Ants		9								
Pill Bugs										

While servicing the stations, data is recorded to monitor the level of bait consumption and/or active foragers found in each station. Heavy or continuous termite feeding activity at a particular site or station is entered into a database, assessed and, if necessary, the building is upgraded to a Tier 1 priority rating. This data can help identify areas of heavy moisture or other conducive conditions that might be proactively addressed.

Pertinent data is also entered into a CAD system so that visuals on areas of high termite concentrations can be noted and evaluated. This helps in the identification of trends, pockets of heavy foraging activity and areas where little activity exists. This can help focus proactive monitoring efforts into areas where they will be most effective.

In 2013, Colonial Williamsburg's termite service costs were reduced 480% when station maintenance responsibilities were transferred from a contractor to in-house staff, allowing a significant increase in the number of properties eligible for treatment in the IPM budget.


Image: Colonial Williamsburg Foundation

Tier 1 — Low risk of infestation

Tier 2 — Moderate risk of infestation

Tier 3 — High risk of infestation

Image: Colonial Williamsburg Foundation

Examples of Tier 1 Qualifications ***(High risk):***

1. The building is one of the 88 original 18th century structures on property

2. The building is a reproduction or office/support buildings with a history of heavy termite activity

3. Conducive conditions are such that monitoring/baiting are unlikely to be effective.

Schedule:

- *Annual inspection of structure*
- *Traditional liquid perimeter treatment*

Advantages of liquids	Disadvantages of liquids
Faster /more thorough results	**Misapplication can result in contamination of soil or water**
Less maintenance	**Requires extensive application equipment**

Image: history.org

Designation

Liquid perimeter treatments are reserved for circumstances where the risk of infestation and damage to an 18th-century historic structure is:

1. Actively occurring

2. Thought to be likely due to:

    a) conditions observed during inspection
    b) conditions observed in monitoring data (Priority 2)
    c) previous history of termite pressure

Such assessments are reviewed and discussed by a committee of architectural and conservation experts who have conferred with an in-house safety and security representative as well as IPM staff .

Image: Ryan Jones, Colonial Williamsburg Foundation and Home Paramount Pest Control

During a Tier 1 preventative liquid treatment (carried out every 7-10 years), the contractor performing the application is required to observe the following steps to ensure safety and efficacy:

Images: Ryan Jones Colonial Williamsburg Foundation

1. Contractor excavates a shallow trench around the exterior perimeter of the structure. This dams the termiticide and pushes it directly against the side of the foundation/footing for precise application.

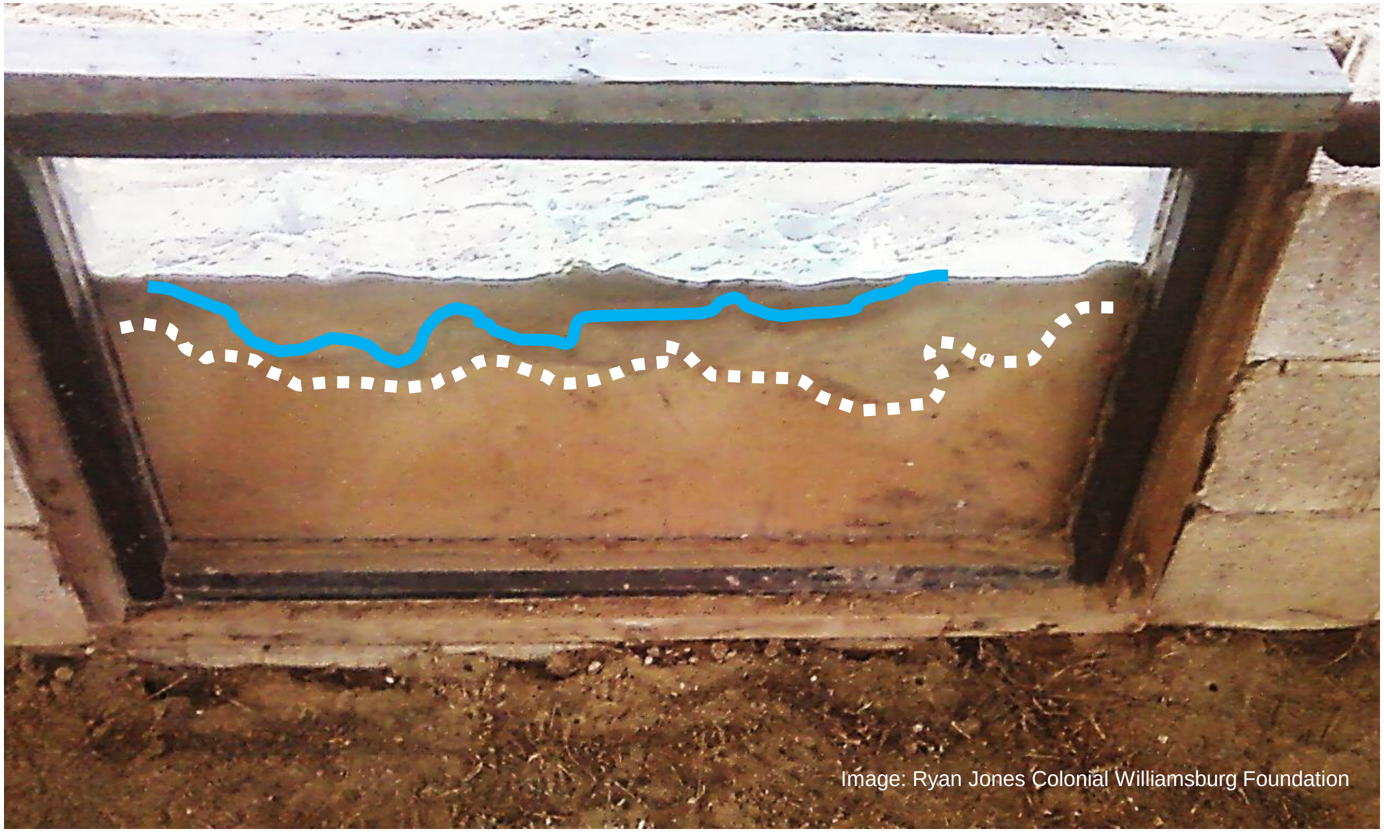
2. Contractor treats the underlying soil and backfill with a special termiticide injector that will apply the product in a narrow band up from the bottom of the footer (or basement foundation).

3. Contractor backfills trench, ensuring that all backfill material has been treated according to label specifications.

Image: Ryan Jones Colonial Williamsburg Foundation

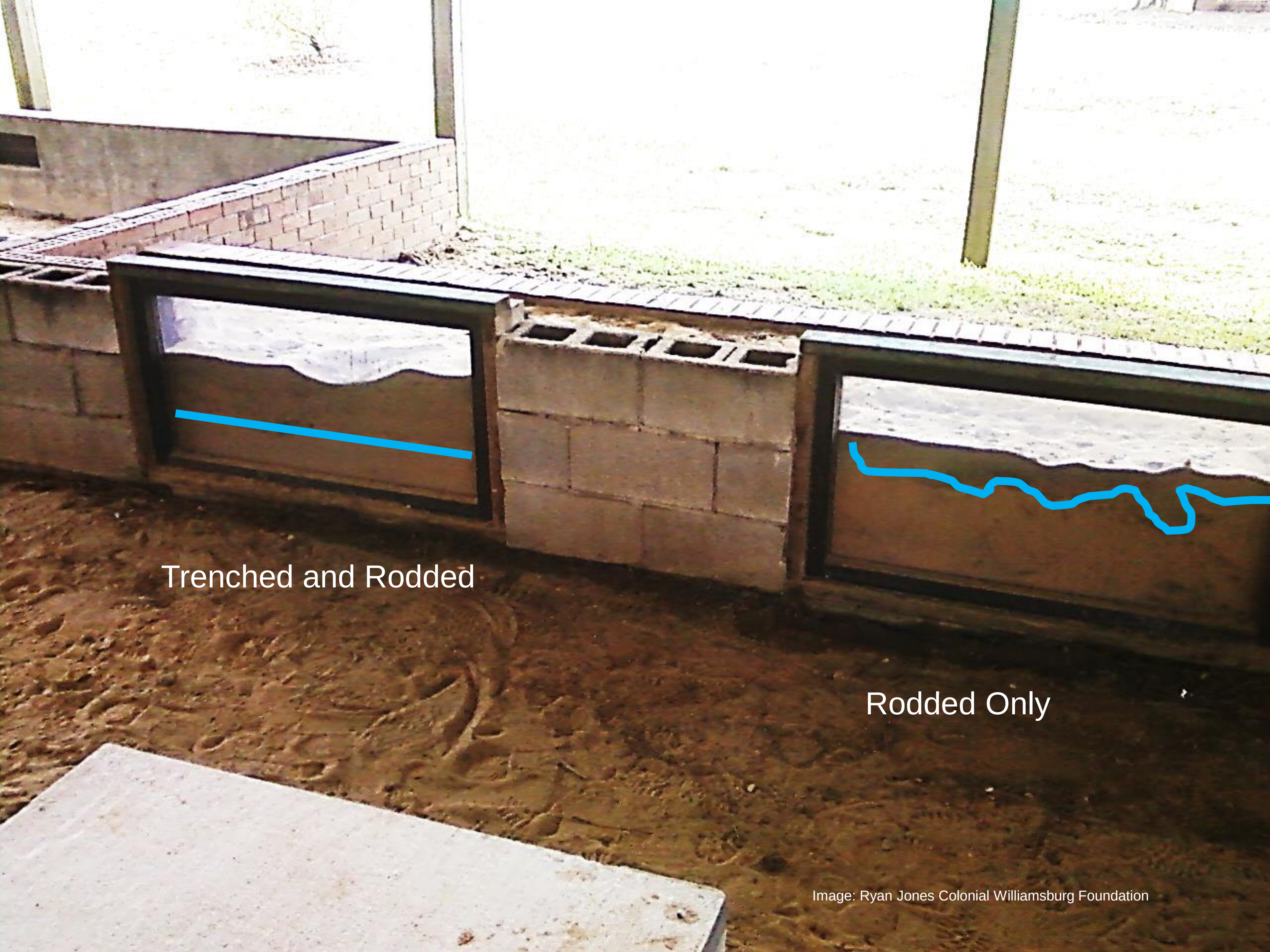
The following images, taken at Clemson University's Apprentice and Master Termite Technician training series 16, underscore the advantages of using the trench/rod method of application in lieu of shortcuts frequently encountered in the termite industry, such as:

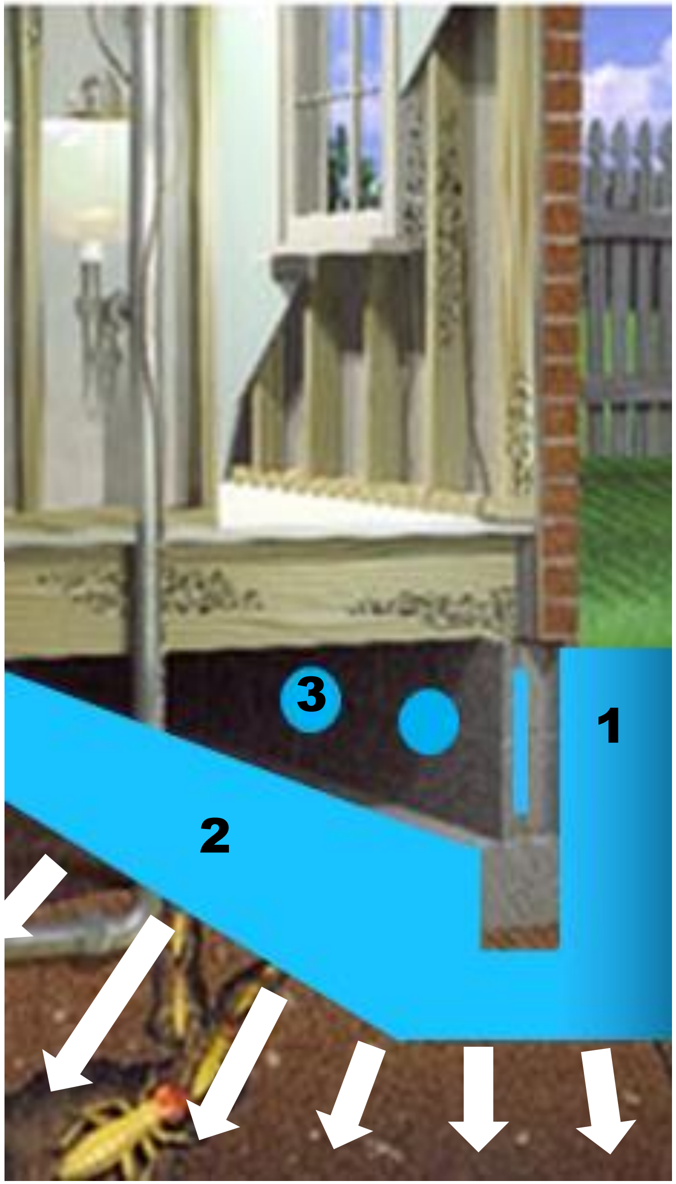
1. Rodding with no trench
2. Flooding the trench without inserting the rod into the soil



In this frame, rodding of the soil was carried out using blue dye and water without using a trench. Notice the uneven distribution of liquid.

In this frame, the soil was both trenched and rodded. Note the more uniform distribution of the blue dye.


Trenched and Rodded
Rodded Only
Image: Ryan Jones Colonial Williamsburg Foundation



Non-Repellant Termiticides

Colonial Williamsburg requires that all liquid treatments be carried out with a *non-repellant* active ingredient, which dynamically changes the itinerary for treatment from the traditional repellant termiticide treatments common in the 1990's.

Why not use repellant termiticides?

As the name suggests, the primary function of a repellant termiticide is to repel foraging workers from the vicinity of a given structure. As such, repellant applications require a near-perfect barrier in order to provide effective protection, necessitating a more invasive and voluminous treatment procedure. A structure that has a simple block foundation with a crawl space would entail the following for an effective repellant treatment: *(See left*)

1. Trench/rod treatment of exterior perimeter of foundation
2. Trench/rod treatment of interior perimeter of foundation (crawl)
3. Drill / inject treatment of hollow block foundation

Even small breaches in the repellant termiticide barrier would be a potential risk, because the primary objective of the treatment is to drive termites away from the structure rather than cause a significant reduction in the invading populace.[17]

Depending on the foundation type and construction of the building, a repellant termiticide application might involve such preparatory mechanisms as trenching inside of crawl space perimeters and drilling holes in hollow block or concrete floors to allow for termiticide injection. This process, though necessary to install a complete barrier, would likely create problems with defacement of original structural elements that exist in a historic structure.

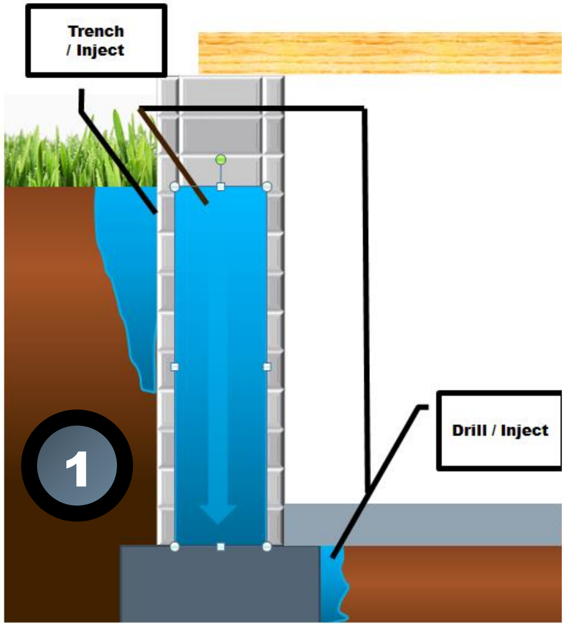
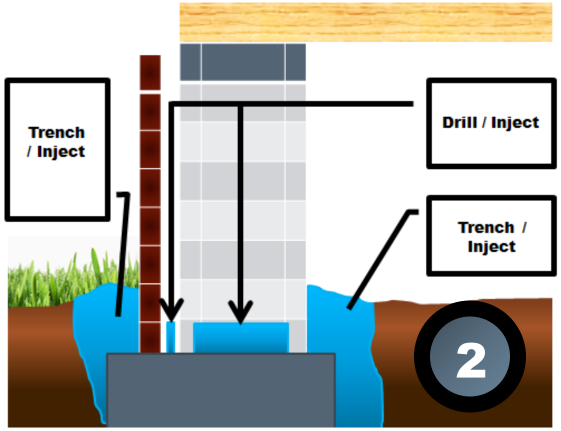


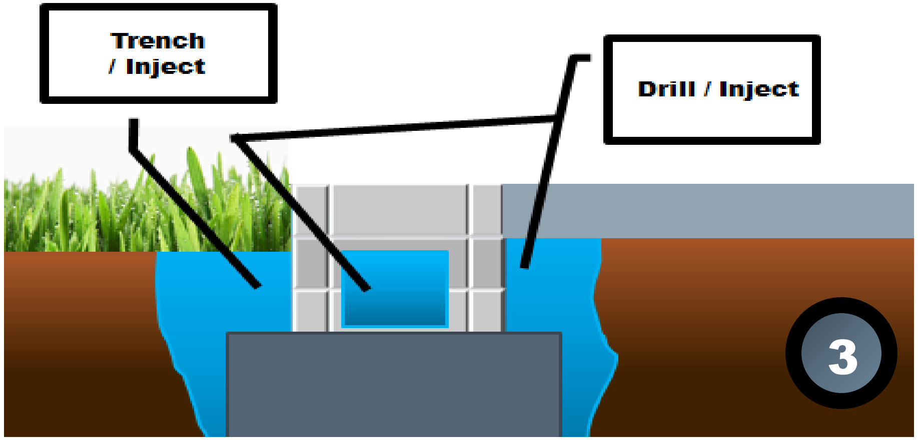
Figure 1: Traditional liquid treatment for basement

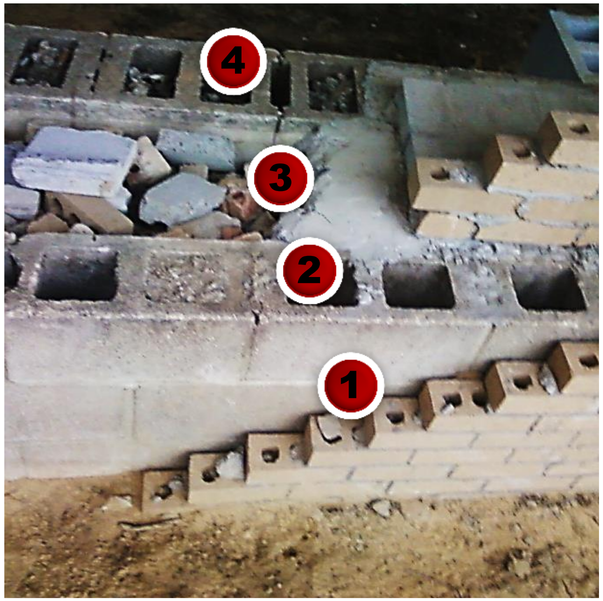
Figure 2: Traditional liquid treatment in crawl space

Figure 3: Traditional liquid treatment for slab foundation

Images: Ryan Jones Colonial Williamsburg Foundation







These images further illustrate the intricacies inherent in the application of repellant termiticides in and around multi-layered foundational elements. In instances of standard residential or commercial structures, a contactor might opt to treat such voids regardless of the product used. With historical structures, however, the likelihood of permanent defacement of the foundational elements must be weighed against the potential for actual termite infiltration. Note that each foundational void (numbered) must be drilled and treated when performing this method of treatment.

Images: Ryan Jones Colonial Williamsburg Foundation

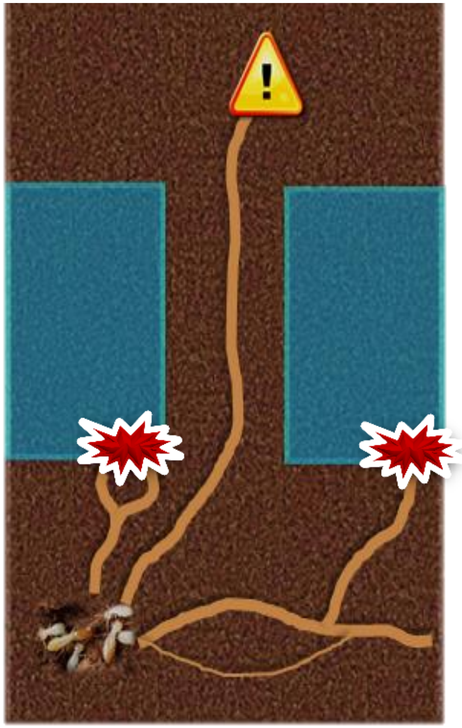


Image 1: Repellant

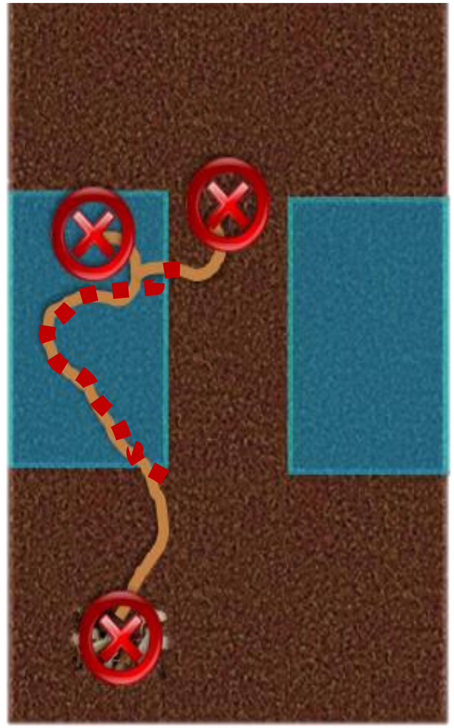


Image 2 : Non-Repellant

Represented in this study are the variations in termite behavior when workers are exposed to both repellant and non-repellant treatment applications. For clarity, the blue squares in Image 1 represent soil treated with a repellant termiticide, while the squares in Image 2 represent soil treated with a non-repellant termiticide.

In Image 1, foraging termites were diverted away from the treatment zone when they encountered the treated soil. However, they continued to forage until a break in the treatment zone was located and exploited. This is a concern when treating structures with complicated foundational elements, as a perfect barrier is often impossible to negotiate despite thorough applications.

In Image 2, the non-repellant application, foraging termites came into direct contact with the active ingredient without knowing they had been exposed. Workers transferred the active ingredient throughout the remainder of the colony both by ingestion and by contact. This led to a rapid reduction of colony population.

With the non-repellant treatment method, an imperfection in the barrier made little or no difference because the foragers were unaware of the residual action of the product in the soil.[18]

Images represent actual photos of study conducted by BASF

A simplified treatment at lower volumes

Because subterranean termites cannot detect non-repellant products and will readily move through treated zones, colony control and prevention can often be achieved with a simplified version of the standard liquid treatment:

1. Trench/rod of the exterior perimeter
2. Inspection of the crawl space/ basement (if applicable)
3. Targeted applications around crawl space piers (if applicable)

This process allows for a 50-75% reduction of termiticide being introduced into the soil and, as an additional benefit, less potential for defacement of historical foundational materials in the process of treatment.

Termite baiting strategies vs. conventional liquid treatments: A clear advantage?

Over the last fifteen years, Colonial Williamsburg has relied on the use of a well-known subterranean termite monitoring/baiting system as its sole means of termite prevention. Though the effort was managed by well-trained and conscientious contractors, efficacy proved difficult to determine with certainty, as the standard for colony elimination in any bait system from a preventative perspective is based on the proliferation and cessation of feeding inside of the station(s).

Images: Colonial Williamsburg

As early as 2002, Dr. Thomas Parker, PHD, an internationally recognized expert witness in WDI litigation, questioned the certainty of gauging colony elimination solely on the cessation of feeding inside a bait station.

“A termite technician may become excited termites have hit a bait station or two, but there are no guarantees the termites feeding in the bait station have any connection to the (structure).Placing a bait matrix in a particular station may wipe out a branch of a particular colony, but it often fails to eliminate the entire colony.

Often termites may feed on a bait station for a while, a bait matrix will be put in place; and the next month (the termite technician) checks the station, he thinks the termites are gone. Does this mean he has wiped out the entire colony? Probably not. There are all sorts of reasons a termite colony may abandon a bait station.”[19]

In Colonial Williamsburg, several failures of its termite baiting system were noted over a two year audit, as is evidenced in the following case studies.

Images: Ryan Jones Colonial Williamsburg Foundation

CWF Site 1:

In the spring of 2012, an in-house inspection was conducted at a historically significant building that was serviced by an outside contractor.

During the inspection, a wooden stoop on the Northeast corner of the structure was found to be heavily infested with subterranean termites. The foraging workers were not only actively consuming cellulose on the underside of the stoop, but had commenced construction of an exploratory tube up the foundation toward the main threshold. Less than two feet away, the bait station that was intended to intercept foraging activity was left untouched.

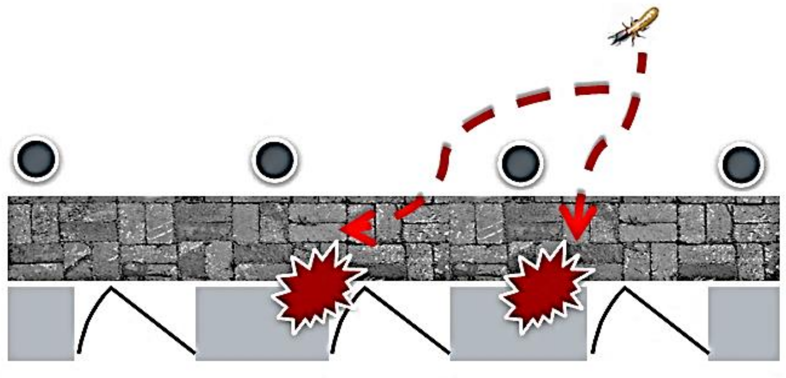
Subsequent follow-ups showed that feeding activity did not begin in the station for at least six months. Since routine maintenance services involved electronic scanning of the stations and a once-yearly inspection of the building itself, the infestation went undetected, as there was no feeding inside of the bait station to trigger the scanner.

Images: Ryan Jones Colonial Williamsburg Foundation

CWF Site 2:

While conducting routine maintenance operations in a one-story tea house in the early spring of 2012, subterranean termites were found tunneling underneath a brick patio to feed on the wooden thresholds of two south-facing doorways. Largely ignored a few feet away were a series of bait stations situated around the perimeter of the patio. Architects and conservation advisors turned down the termite contractor's request to wait several months until the baits had been given sufficient time to work, siting the potential for continued destruction of a historical structure. Replacement wood was pretreated with a borate salt before installation, making future WDI infestation less likely.

Image: Ryan Jones Colonial Williamsburg Foundation

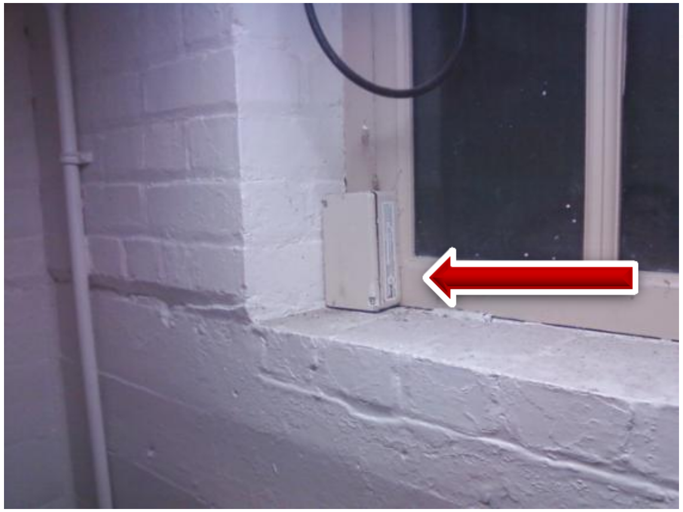


CWF Site 3:

A small wooden structure was transported from its original foundation to another location a mile away. A few days after arrival, a subterranean termite colony was found thriving near a small leak on the second floor, indicating a probable failure of the bait stations at the original site.

Aboveground (AG) bait stations were installed on the second floor to correct the problem. Activity ceased in the stations after more than six months of heavy feeding.

Image: Ryan Jones Colonial Williamsburg Foundation



These and other documented instances of system failure were a catalyst for discussions among staff who held a vested interest in protecting Colonial Williamsburg's assets. Research was conducted for nearly two years into alternative methods of control that would offer more dependable means of protection against the possibility of WDI infestation while still maintaining a focus on good stewardship of the environment. The majority of pitfalls in the existing termite bait system were found to include two primary deficiencies:

1. Stations were being installed in response to existing termite infestations rather than being utilized as a proactive means of early detection and control.

2. Stations were essentially being used as a stand-alone method of prevention instead of a tool in a holistic IPM approach.


Scott Bauer, USDA Agricultural Research Service, Bugwood.org

A collaborative restructuring of the termite prevention effort resulted in the following improvements:

1. Increased emphasis on detailed site inspections and deterrence through non-chemical intervention.
2. Institution of a broader range of treatment options – including the continued use of preventative termite bait applications and the addition of liquid perimeter treatments - that would be custom-matched to the circumstances of each building.
3. In-house accountability for the methods and implementation of termite deterrence
4. Detailed record-keeping and documentation of termite activity, moisture problems, and other potentially chronic deficiencies that would likely lead to structural damage.

This type of enhanced inspection schedule was cost-prohibitive under the confines of what would be feasible in most termite prevention agreements, but was found to be a reasonable goal when undertaken by an in-house certified termite specialist who would also be trained in the basics of conservation.

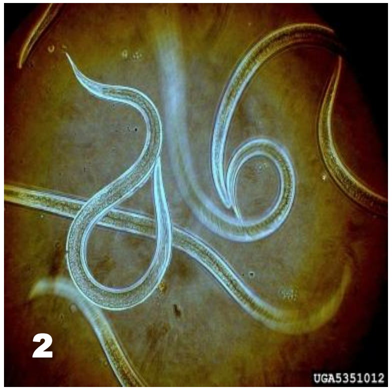
To operate in a partnership with Colonial Williamsburg, contactors were interviewed to perform the liquid perimeter treatments, while responsibility for maintenance of Tier 2 bait stations shifted entirely to in-house IPM staff. With this template in place, attention broadened to exploration of alternative treatments that have potential to aid in the reduction of termiticide application.

These include:

1. The use of targeted microcrystalline-cellulose bait placements for treatment inside of active termite galleries and mud tubes, including those found in Tier 2 monitoring stations. The expanded label on this product allows for cost-efficient treatment of secondary infestation sites like fence posts, whisky-barrel waste receptacles, and other areas that harborage and entice termite colonies to move closer to historic buildings.
   (Image: BASF)

2. The use of parasitic nematodes to supplement monitoring/baiting efforts where termite activity is moderate to high but is not deemed to be an immanent threat to a historical structure. (Image:nematode *Steinernema scapterisci* David Cappaert)

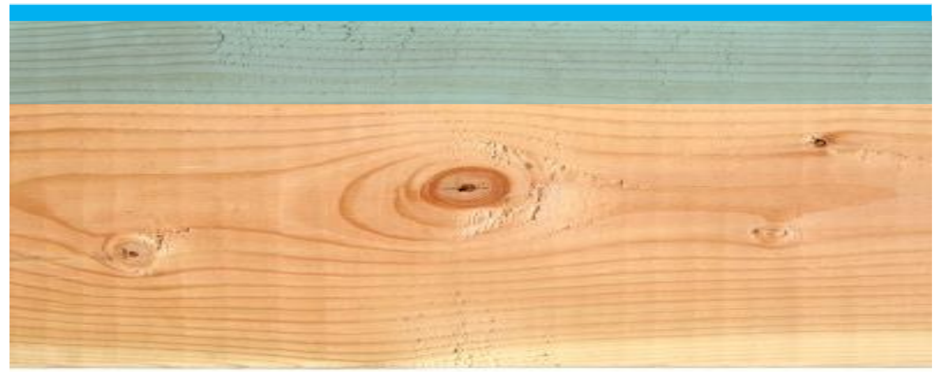
3. The use of liquid termiticide products that have been labeled as reduced risk (no EPA designated caution labeling required).
   (Image: Ryan Jones CWF)



Borate salt treatments have also been applied to exposed raw wood structural elements to reduce the likelihood of termite/WDI infestation. Treatment is typically conducted pre-construction (see image 1), but can be instituted whenever raw wood is exposed.

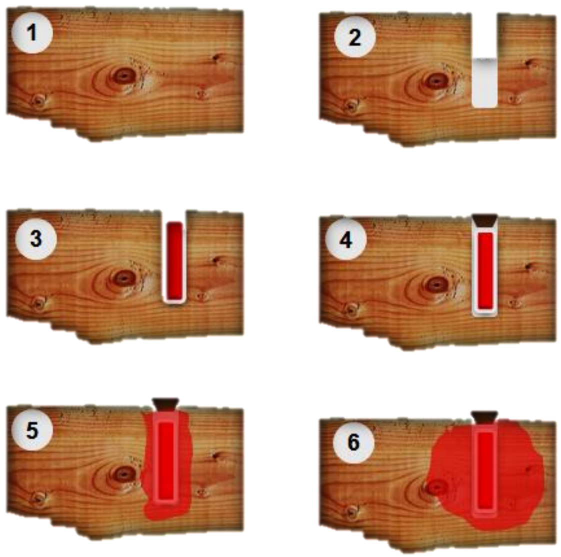
Image: University of North Carolina

Borate treatment of flooring

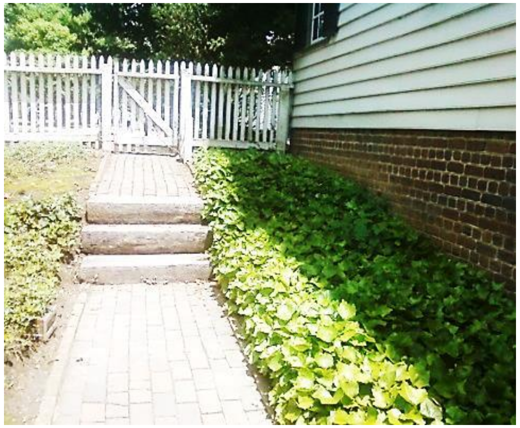


In January 2013, borate salts were applied to raw wood during a floor replacement phase at the DeWitt Wallace Art Gallery. In addition to preventing subterranean termite activity, borate salts help prevent the infiltration and reproductive cycle of wood-bring insects like powder post beetles.

Image: Ryan Jones Colonial Williamsburg Foundation



Impel rods that diffuse borate salts into raw wood are used to prevent damage in dense building materials like stoops and stairways that will remain outdoors or in areas of wood/ground contact. Rods are inserted into pre-bored holes in raw wood. After being capped, the borate salts in the rods diffuse into the wood.



In addition, many reproduction and restored structures on property were built using a termite shield between the foundation and the sill plate.

While this shield does not guarantee that termite infestation will be detoured, its presence forces termites to build tubes in areas easily seen with the naked eye.

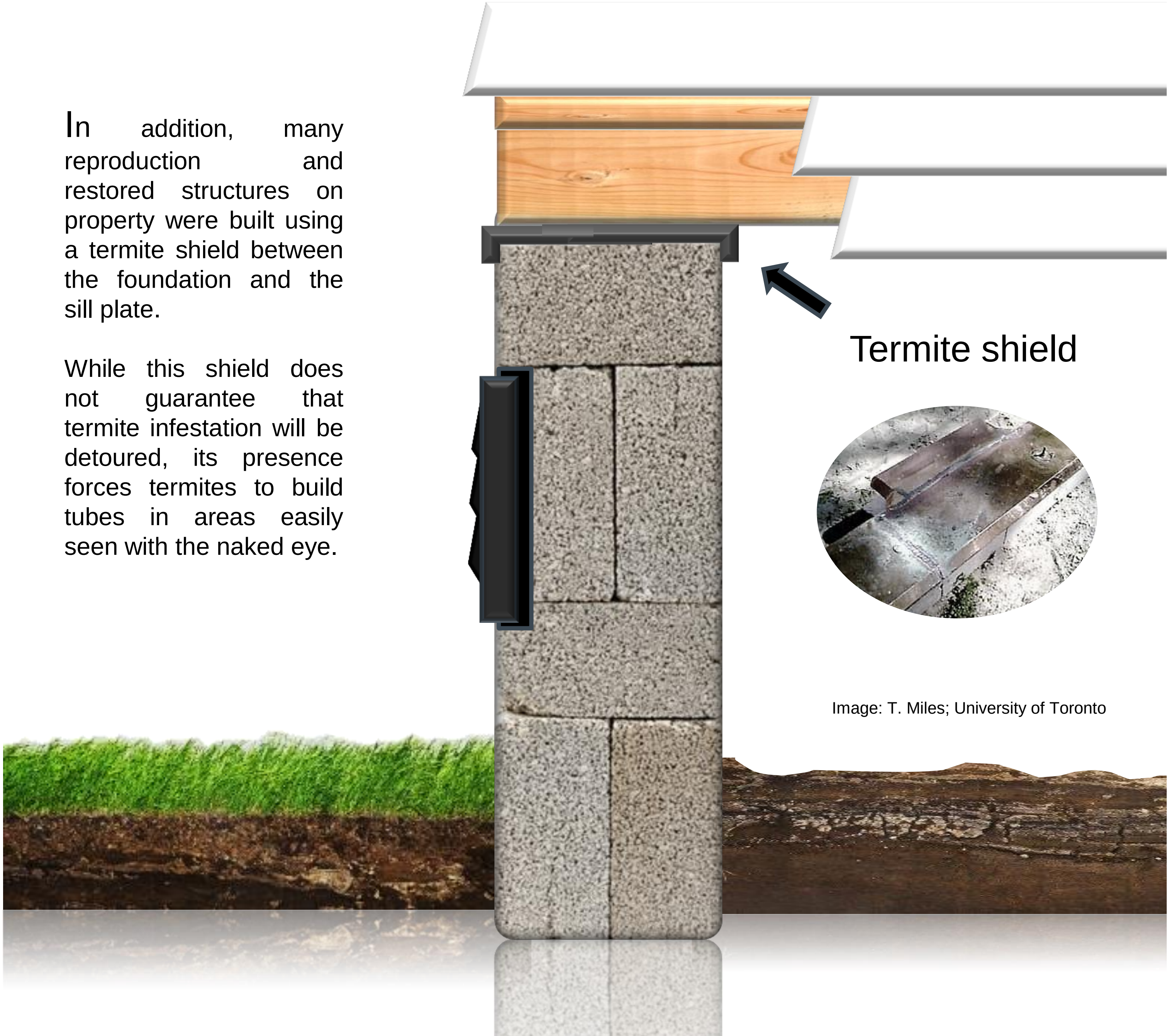


Image: T. Miles; University of Toronto

Within Colonial Williamsburg's three-tiered inspection system, much room is left for fluctuation as circumstances dictate. Each building is evaluated individually and decisions are made by an IPM committee with the intention of maintaining a responsible balance between least-toxic means vs. competent preservation of historical artifacts.

This approach will continue to evolve, with roots firmly established in the principles of IPM to ensure that Colonial Williamsburg's historical resources will be available for generations to come.

Colonial Williamsburg®

"That the future may learn from the past"

References:

1. Parker, Dr. Thomas A . “Termite Basics.” *Stop Termites Before They Eat Your Wallet: A Behind-the-Scenes Look at the Professional Termite Control Industry,* 2002. p19. Print

2. Global Environment Facility “Termiticides in China”http://www.thegef.org/gef/POPs_Termiticides_China

3. Parker, Dr. Thomas A . “Termite Basics.” *Stop Termites Before They Eat Your Wallet: A Behind-the-Scenes Look at the Professional Termite Control Industry,* 2002. p31. Print

4. Victorian Tree Industry Organisation “*THE RELATIONSHIP BETWEEN SOIL MOISTURE CONTENT AND THE EFFECTS ON TERMITE FORAGING ACTIVITY*” PDF http://vtio.org.au/Glenormiston/Five%20termite%20studies%20-%20Dr%20B%20Ahmed.pdf

5. Petr Ptáček, Jiří Brandštetr, František Šoukal and Tomáš Opravil (2013). Investigation of Subterranean Termites Nest Material Composition, Structure and Properties, Materials Science - Advanced Topics, Prof. Yitzhak Mastai (Ed.), ISBN: 978-953-51-1140-5, InTech, DOI: 10.5772/55145. Available from: http://www.intechopen.com/books/materials-science-advanced-topics/investigation-of-subterranean-termites-nest-material-composition-structure-and-properties

6. Thorne, Dr. Barbara L. “Kings and Queens of the Underworld” *PCT Magazine*, May 1, 1996 Print.

7. Ogg, Clyde; Ogg, Barbara; Kamble, Shripat; Ferraro, Dennis. University of Nebraska, Lincoln Extension “Biology; searching for food” *Subterranean Termites: A handbook for Homeowners.* May, 2006. p7. Print

8. Parman V[1], Vargo EL. Department of Entomology, North Carolina State University, Raleigh, NC *Population density, species abundance, and breeding structure of subterranean termite colonies in and around infested houses in central North Carolina.* J Econ Entomol. 2008 Aug;101(4):1349-59.

9. Kimberly McManamy1,2, Philip G. Koehler1, Deanna D. Branscome1,3& Roberto M. Pereira1* : University of Florida, Department of Entomology and Nematology. *Wood Moisture Content Affects the Survival of EasternSubterranean Termites (Isoptera: Rhinotermitidae), UnderSaturated Relative Humidity Conditions*

10. **Thorne, B.L. .** Biology of Subterranean Termites of the Genus *Reticulitermes*. Part I, Research Report on Subterranean Termites, pp. 1-30. National Pest Control Association, Dunn Loring, Virginia.1998

Also: http://www.bugsinthenews.com/Subterranean%20Termite%20Food%20Consumption.htm

11. Parker, Dr. Thomas A . “Termite Basics.” *Stop Termites Before They Eat Your Wallet: A Behind-the-Scenes Look at the Professional Termite Control Industry,* 2002*.* p19. Print

12. Stephen Tvedten “How to Permanently and Safely Control all Wood Destroying Organisms” *The Best Control II .* Chapter 36; p1348

Also: http://www.syix.com/emu/index.htm

13. Parker, Dr. Thomas A . “Termite Basics.” *Stop Termites Before They Eat Your Wallet: A Behind-the-Scenes Look at the Professional Termite Control Industry, 2002*

14. Parker, Dr. Thomas A . “Termite Basics.” *Stop Termites Before They Eat Your Wallet: A Behind-the-Scenes Look at the Professional Termite Control Industry,* 2002*.* p113. Print

15. Idham S. Harahap, Eric P. Benson, Patricia A. Zungoli and Hoke S. Hill Jr. *IMPACT OF SEASONAL TEMPERATURES AND RELATIVE HUMIDITY ON CELLULOSE CONSUMPTION BY RETICULITERMES FLAVIPES AND RETICULITERMES VIRGINICUS(ISOPTERA: RHINOTERMITIDAE)* 2005 p182. Print

16. http://www.clemson.edu/cafls/departments/esps/research/urban/mttschool.html

17. Parker, Dr. Thomas A . “Termite Basics.” *Stop Termites Before They Eat Your Wallet: A Behind-the-Scenes Look at the Professional Termite Control Industry,* 2002*.* p113. Print

18. http://www.termidor.com.au/all-about-termidor/non-repellency

19. Parker, Dr. Thomas A . “Termite Basics.” *Stop Termites Before They Eat Your Wallet: A Behind-the-Scenes Look at the Professional Termite Control Industry,* 2002. p118-119. Print