

WET STORAGE OF WINDBLOWN CONIFERS IN GERMANY

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INTRODUCTION

On 1 August 1975, northwesterly winds reaching a maximum velocity of 180 km/h passed over parts of the South Island of New Zealand, affecting some 44 000 ha of plantations and shelterbelts in the Canterbury area (Wilson, 1976). Approximately 10 700 ha of merchantable radiata pine between the ages of 40 and 45 were blown down, comprising an estimated sawlog volume of about 2.2 million m³. To preserve the quality of the sawlogs, a decision was made to experiment with sprinkler storage of some 14 500 m³ of logs at Balmoral Forest close to a supply of windblown logs, water and drainage, and reasonably close (approximately 90 km) to processing industry in Christchurch.

Details of the operation, including establishment, maintenance and results were recorded by Clifton (1978, 1983); Hayward (1981) carefully investigated the biological and technological properties of the stored logs together with the microbial colonisation after four years running. The treatment of small stored logs for fence-posts following air drying and preservative treatment is described by Lay Yee (1981). Generally the results showed this to be a very successful operation in preserving quality in this type of material, following blowdown.

Clifton (1978) noted that the decision to undertake storage of logs for a period up to four and a half years was prompted by favourable experience in a similar situation in the Federal Republic of Germany following a severe windstorm in 1972. Subsequent wet storage of approximately 1.39 million m³ of logs was the largest storage test made up to that time. Detailed results of this earlier work are scattered through a number of

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German publications, prompting presentation of a brief resume describing the operation and its results, to serve as a reference for dealing with future catastrophes of this type.*

THE 1972 WINDSTORM AND ITS EFFECTS

On 13 November 1972, a windstorm with gale velocities to 200 km/h struck northwestern Germany, particularly lower Saxony, and flattened more than 100 000 ha of forest, 10% of the total forest area. These stands were so heavily affected that clearing and re-forestation became necessary, involving, all told, 17.6 million m³ of all age classes and comprising 15.9 m³ of merchantable timber. Most seriously affected was pine (*Pinus sylvestris*), accounting for a loss of more than 10 million m³. No storm damage of such magnitude had occurred in European forests prior to this time and experience was lacking in dealing with this catastrophe.

An earlier storm of much smaller extent struck southern Denmark, northern and southern Germany in 1967. Experimental wet storage — either under sprinklers or in lakes — had prevented wood deterioration in logs for a number of years (von Aufsess and von Pechmann, 1970; Liese, 1973; Molteson, 1971; Molteson *et al.*, 1974). Based on this early experience, the decision was made to attempt large-scale wet storage of logs from the 1972 windstorm in an effort to maintain timber quality for some time. This latter project, furthermore, was instigated to reduce market pressure and resulting price drop following this timber loss, and to ensure a continuing supply of logs for sawmills in the affected region during the period of storage.

In total, 1.39 million m³ were placed under wet storage, specifically in 93 sprinkler yards and in five lakes/ponds (see Figs. 1, 2). Previous tests had shown that lakes and ponds are less favourable for storage on several counts:

- (1) They are limited in availability
- (2) They can hold approximately 1 000 m³/ha compared with approximately 10 000 m³ under sprinklers
- (3) Loading and unloading involve technical problems
- (4) Loss due to sinkers may occur (particularly with European beech, *Fagus sylvatica*).

*Molteson (1977) describes additional experience with the wet storage of roundwood in Denmark.

- (5) Moisture content in some stems may not become sufficiently high for protection, particularly if stored in bundles (Kartsedt and Loetz, 1970)
- (6) Water pollution due to removal of bark and the leaching of extractives may affect fish and sometimes leads to unpleasant odours.

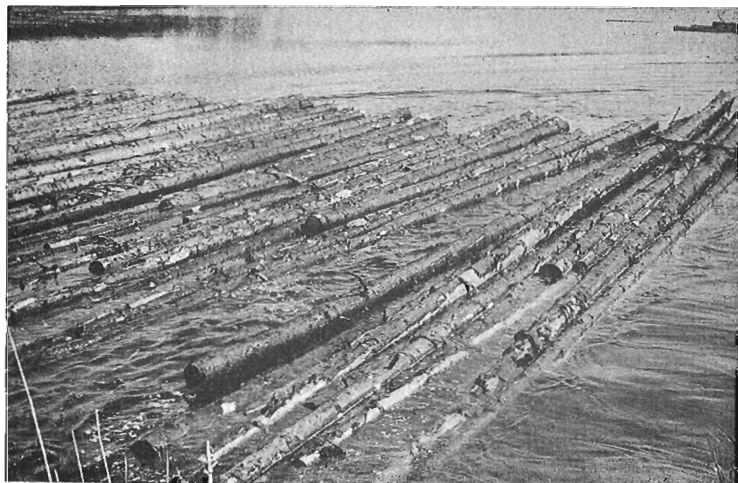


FIG. 1: *Water storage of spruce logs.*

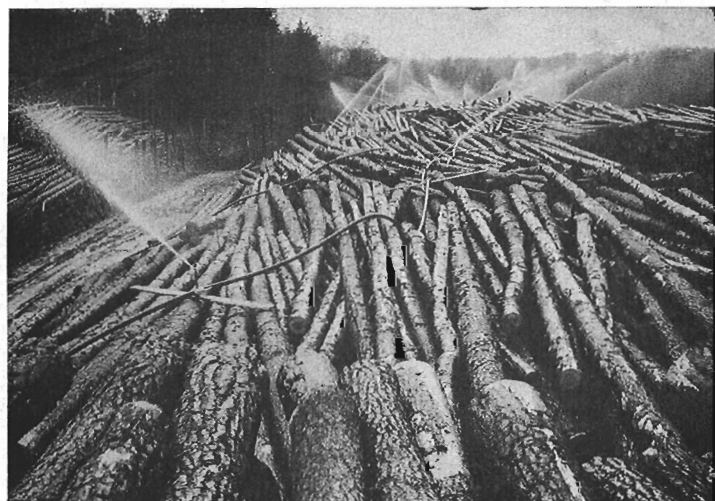


FIG. 2: *Wet storage of pine logs under sprinklers.*

SPRINKLING LOG PILES

The procedures used for clearing up the windblown forests, for transporting logs, and erecting the log piles are documented in detail (Arnold *et al.*, 1976; Kremser *et al.*, 1977, 1979, 1980). Selection of suitable storage sites was governed mainly by the following criteria:

- (1) Availability of water and adequate drainage
- (2) Access to energy
- (3) Transportation distance and road access
- (4) Soil conditions
- (5) Possibilities for site extension
- (6) Convenience for later utilization of logs

Capacity for storage at a given site had a smaller influence on overall cost than did transport distance. Of 50 sprinkler locations in flat terrain, only five were less than 1 ha in extent with a median size of 2.7 ha (range 0.3 to 7.2 ha). Thirty-four storage sites, located in hilly regions with an average size of 0.7 ha (0.03-2.9 ha), were found to hold more timber because of storage over creeks. The capacity for timber storage in any one location varied between 8 000 and 60 000 m³.

Storage piles had an average width of 25 m (15-50 m), depending on type of sprinkler, and a height of 4 to 4.5 m. Most



FIG. 3: Sprinkling over a creek in the Harz Mountains.

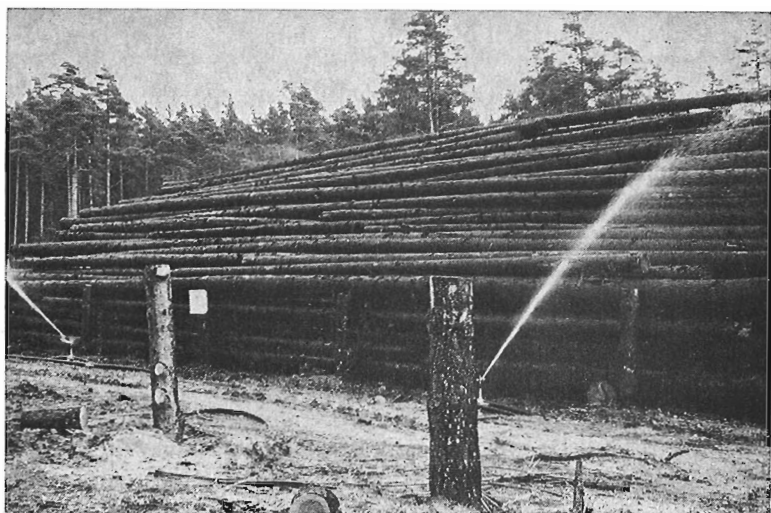


FIG. 4: *Side supports of a pine log stack.*

were arranged longitudinally to provide easier access for handling logs. In some locations supports were inserted on the sides of the pile to provide a greater compactness. It was found, however, that the weight of logs and wetting of the soil often led to sideways movement as is illustrated in Fig. 4. Log supports placed on the ground at 90° to the log axis afforded better handling and



FIG. 5: *Supports on the ground proved unsuitable.*

increased air circulation owing to a "chimney" effect; however, this practice frequently led to partial drying and subsequent deterioration of logs (Fig. 5). During storage these supports were often pressed into the soil, suggesting placement directly on the ground for best results.

Lengths of individual piles depend upon length of the longest stem. Logs should be stacked together as closely as possible and even-ended — spacing between piles facilitates handling. The angle of repose averaged 35° with pine and 45° with spruce, *Picea abies* (because of straighter stems).

A prerequisite for wet storage of logs is obviously the availability of water. In these operations most of the water came from wells and some from surface waters, especially in mountainous regions. Water quality apparently does not influence its "preservative" effect on wood, but must be clean enough to prevent blocking of sprinklers owing to contamination (iron) or corrosion of piping. An average log pile of 20 000 m³ requires approximately 80-100 m³ of water per hour to supply the required 40 mm/m²/day. Excess water obviously contributes to excessive cost.

SPRINKLER SYSTEMS

Danish experience indicated that a daily precipitation of 44 mm/m²/day in summer months provided good protection to the logs (Moltesen, 1971). Sprinkler installations were thus designed for a minimum capacity of 40-50 mm/m²/day of sprinkled water per day. Sprays were operated mostly during daytime, in the summer (up to 16 hours), at an hourly rate of at least 2.5-3 mm/m². During freezing weather, the system was closed since ice on the logs forms a natural protection against evaporation. Sprinklers were operated mainly at twenty-minute intervals but sometimes these periods were increased to forty-five minutes. It is essential to maintain a nearly water-saturated atmosphere around the log pile including the sides, at which locations special sprinklers were found necessary.

Sprinklers were of the oscillating or rotary type having nozzles between 3.5 and 5.6 mm in diameter and with a throwing radius of between 12 and 16 m at a working pressure of 2-5 atm. Several materials were used for spray lines, mostly galvanised flat steel but others of polyethylene, polyvinylchloride (PVC), and aluminium proved satisfactory. Average lengths were six metres, fitted with quick-coupling ends to facilitate handling of the line. The spray pipes were fastened directly to the logs by means of clamps.

For calculating the number of pipe-lines and the distance between individual sprinkler heads, the general rule is that all timber should lie within 75% of the calculated spray radius area. It was found that most sprinklers would cover approximately 12 m but that prevailing winds have a considerable influence on water distribution and must be accounted for by adequate spacing.

RESULTS OF WET STORAGE

(1) Moisture Content of Wood

The decisive factor for successful protection of logs in storage is the attaining and maintaining of a sufficiently high moisture content in the log. Thus, windblown trees should be cut into logs and transported to the storage site as quickly as possible after the storm. Our experience indicates that in summertime logs should be under sprinklers within three weeks after felling, and during autumn and winter not longer than four to six weeks, depending somewhat on weather conditions. Sprinkling should be started while preparing the stock-piles.

For *Pinus sylvestris* (basic density of 0.49 cm³) it was found that a minimum sapwood moisture content of 100-120% (based on oven-dry weight) was essential to ensure protection. Approximately 4 000 measurements from borings have shown that sapwood moisture content can be raised only slowly during the sprinkling because of air trapped in the longitudinal tracheids. In the heartwood, which comprises about 50% of the cross-section, moisture content after storage remained near its average low level of approximately 40%, increasing only slightly during storage. Therefore the heartwood is at a favourable moisture content for the growth of decay fungi. Consequently, incipient decay in windthrown logs because of heart-rot fungi must be carefully excluded, otherwise decay will spread even in sprinkled logs as we have observed with *Fomes annosus* and *Sparassis crispa* (Peck and Liese, 1974). The moisture content of *Picea abies* logs showed only a moderate increase during sprinkling (von Aufsess *et al.*, 1974).

(2) Wood Quality

Selection of logs for wet storage must be restricted to high quality logs with a high moisture content and free of fungal infection. Bark damage with subsequent partial loss of moisture and incipient decay predispose a log to loss in value during stor-

age. Results of storage indicated that logs attaining and retaining the required level of moisture in sapwood provided by adequate sprinkling, did not show any bluestain or the presence of wood destroying fungi during a storage period of up to five years. Although log-ends became covered in the first few months of storage with slime fungi of a striking yellow-red colour and later with algae and mosses, cutting even a few millimetres beneath the surface showed wood of original colour and appearance (Figs. 6, 7). Maintenance of wood quality indicated in earlier reports of smaller scale tests were confirmed up to the period of observation in the larger tests embracing several years. Poorly sprinkled logs with a low moisture content showed a reddish-brown discoloration on the ends and sides primarily due to *Stereum sanguinolentum* which produced fruiting bodies after approximately one year. The common fungus *phlebia* (*Peniophora gigantea*) occurred sporadically.

Wood subjected to long-time storage under sprinklers will be intensively invaded by bacteria. These organisms selectively attack the pit membranes of the ray cells and of the bordered pits between the longitudinal tracheids. After long-time storage of 3-4 years, there appears to be an incipient alteration of the tracheid cell wall. To date there is no positive evidence on the cause of this action but it is thought to be either biological, chemical or a combination of the two. The isolation of numerous

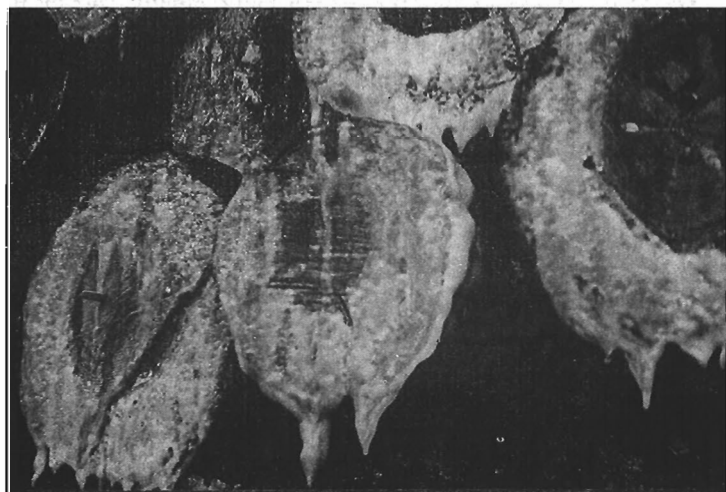


FIG. 6: Log ends covered by slime fungi during the first few months.

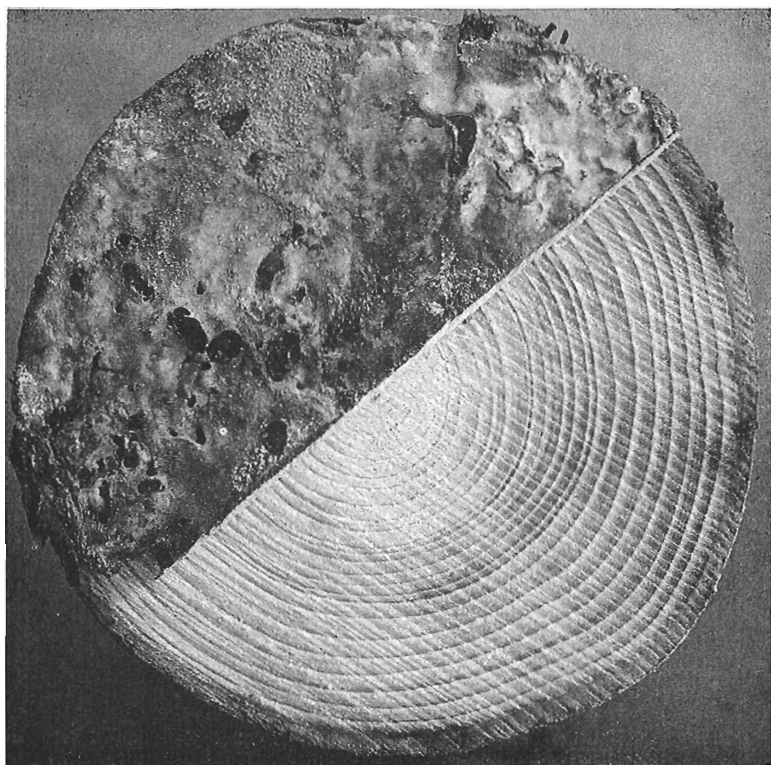


FIG. 7: Wood quality under the cover of algae and moss appears fine.

bacterial strains from pine and spruce (Liese and Karnop, 1968; Karnop, 1972a,b) and from beech (Berndt and Liese, 1973) supplement earlier compilations of bacteria infesting wood (Fogarty, 1973).

Bacterial attack on bordered pits is confined to the sapwood where pit membranes consist only of pectin and cellulose and are still unligified. No pit degradation in the heartwood has been observed, perhaps because of the encrustation of heartwood pit membranes with polyphenolic materials during heartwood formation. (Bauch *et al.*, 1968).

The enzymatic degradation of pit membranes leads to greater porosity, increasing the rate of drying and subsequent preservative treatment. Thus, the penetration of preservatives into refractory species such as spruce can be improved (Dunleavy and Fogarty, 1971) and the bleeding of creosote-treated pine poles may be prevented. Pit degradation within sapwood is often

irregular, however, leading to undesirable over-absorption with pine species, presenting an unacceptable appearance when stained in finishing operations. The effects of pit degradation are more pronounced in water storage than in sprinkler storage (Willeitner, 1971). It has been generally assumed that water-stored timber is less susceptible to bluestain fungi following storage since the ray cells have lost a large portion of their nutritional value to bacterial action. However, laboratory tests with samples from pine sapwood after several years' sprinkler storage have shown that such timbers can still be infected and discoloured by bluestain fungi.

A few of the stored logs showed larvae of wood-boring insects — *Myelophilus piniperda*, *Pissodes pini*, *Hylobius pini* and *Trapodendrium lineatum*. Egg deposition occurred either on the down trees in the forest prior to salvage, or in logs in the stacks in cases where water sprinkling was insufficiently complete. Larval development was apparently unmodified by sprinkling since the beetles emerged. On well-sprinkled logs no insect attack was observed during the whole period of storage (Peek and Liese, 1974).*

(3) Abiotic Discolorations

Spruce logs stored for as short a period as two years and longer frequently showed staining to a darker colour in the outer 5-10 mm of the stem (von Aufsess *et al.*, 1974). The time sequence of this discoloration has yet to be determined but the cause is apparently flavotannins, which diffuse into sapwood from the bark (Adler, 1951). According to Morgan and Orsler (1968) the hydroxystilbene piceatannol darkens under the exposure to light. This marginal discoloration has little effect on sawn timber as most remains in the slab. The use of slabs and small logs for pulp, however, creates problems since the wood turns greenish at first and later brown. Mechanical pulps discoloured in this manner are more difficult to bleach with dithio-mil or peroxide and degrade to a yellow colour faster than normal wood (Loras and Wilhelmsen, 1972). Spruce discoloured by these tannins is not suitable for the sulphite pulping process; Erdtman (1940) attributes the poor cooking in this process

**Pinus radiata* logs stored under water sprays in Balmoral Forest were attacked by the pinhole borer (*Platypus apicalis*) which most likely infested logs stranded near the storage sites by floods of the Hurunui River (Milligan, 1982).

to a lignin-phenolic condensation. Tannin discoloration of this type can also occur in pine but it generally extends deeper into the sapwood than in spruce and is not as regular in its presence in stored pine logs.

In European beech (*Fagus sylvatica*) deep discolorations were not apparent after long-term water/sprinkler storage of almost three years. In drying sawn timber from the stored logs, however, all surfaces exposed to the air turned a brownish-red, apparently caused by a phenolic substance migrating from the vacuoles of dead parenchyma cells into the surrounding wood tissue. During drying of the timber, these phenolic materials are transported to the surface with the evaporating water and there oxidise to dark-coloured phenolic polymers. Experience has shown that this discoloration of water-stored beech can be prevented by air-drying to a moisture content of 50-60% before processing (Höster, 1974).

(4) Mechanical Properties

Forest trees felled or broken by windstorms have undergone severe stresses which may have led to internal failures, sometimes difficult to recognise (slip planes in secondary tracheid walls). Short fractures and transverse compression failures in logs and timber from windblown areas are well known. The possibility of damage of this type to the logs must be considered in judging residual strength properties of timber after wet storage.

The strength properties of windthrown spruce logs have been investigated after three and five years' water storage (Adolf *et al.*, 1972, 1974) and of pine after four years' sprinkler storage (Peek and Liese, unpublished). Reductions of up to 10-15% in impact strength, bending strength and compression strength were found after three years' wet storage with no further increase after five years. Swelling-anisotropy was increased about 15% in this period. Modulus of rupture and modulus of elasticity after four years' sprinkling were sufficiently high to satisfy the standard requirements for marine (boat) timber for which the level is higher than the construction timber requirement. It was thus concluded that no significant strength reduction affecting later utilisation had occurred in stored logs even after five years, provided the timber did not contain storm or handling failures prior to storage and had been maintained at a sufficiently high moisture content to prevent biological deterioration. Moltesen *et al.* (1974) drew similar conclusions for spruce logs after four years' sprinkler storage with regard to maintenance of strength properties.

(5) Decay Resistance and Ease of Treatment

Laboratory tests on the decay resistance of air-dry pine after three years of sprinkling revealed a marked increase in ease of fungal deterioration (Peek and Liese, 1979). Weight loss due to degradation of sapwood by the fungus *Gloeophyllum abietinum* after six weeks of 25% compares with only 8% for freshly cut timber; and losses to over 60% at 24 weeks compared with 20% weight loss for freshly cut timber. This increased susceptibility to decay may be attributed to a synergistic effect of bacterial pre-colonisation and leaching of some wood components. Heartwood weight loss due to the fungus *Lentinus lepideus* at six weeks averaged 15%, compared with 10% of controls, and after 24 weeks stood at 50%, compared with 40% for freshly-cut timber. These increases may be caused by loss of certain toxic extractives from the heartwood.

The preservative treatment of sprinkled pine sapwood samples (15×25×50 mm), following procedures given in DIN 52 176* with the preservatives copper chrome arsenate (CCA) copper chrome borate (CCB) and copper fluoride (CF) salt formations revealed no significant differences in uptake of solutions contrasted with normal unstored sapwood (680 l/m³ compared with 670 l/m³, respectively). Laboratory leaching tests of these treated samples according to DIN 52 172 and bio-assays with *Coniophora puteana*, *Poria placenta* and *Gloeophyllum trabeum* showed that a solution strength as applied in practice afforded full protection, obviating the need for employing higher concentrations in the preservative treatment of sprinkler-stored timber. Sublethal concentrations of the tested CCA and CF salts showed greater decay for sprinkled samples than for fresh material whereas no difference between the two were found with CCB impregnation (Peek and Liese, 1977).

(6) Effects on Water Quality

The authorisation to install sprinkled log yards was often linked with a requirement to investigate and monitor quality of the runoff (back) water, because no information was available on the possible effects on the environment. Several hundreds of water samples were taken at different locations and at different intervals during the initial weeks and months of sprinkling. The values for chemical oxygen demand (COD) of the back-water

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increased from about 50 mg COD/l to 350 mg COD/l owing to carbohydrates leached from bark and wood. With further sprinkling, the load of organic solutes contributing to COD decreased to nearly negligible level after three months (to approximately 70 mg COD/l).

For sprinkled storage yards situated near or over streams, excess water (back-water) with relatively high amounts of dissolved material mixed readily with fresh stream water after a few hundred metres of flow. No contamination could be found at distances of more than 1 000 metres downstream from the storage area. For stagnant runoff from sprinkled timber piles, the major portion of contaminating materials is likely to be absorbed in the soil and decomposed by micro-organisms (Peek and Liese, 1977). From these results and the lack of complaints received during these tests, it can be concluded that sprinkling yards have no detrimental effect on surface and ground water systems even over several years of use.

(7) *Marketing of Sprinkled Logs*

After the water sprinkling of logs to maintain their quality became an accepted practice, there were no marketing difficulties with the acceptance of logs and lumber treated by these procedures (von Aufsess *et al.*, 1974). Sprinkled logs could be sawn at faster feed rates and with fewer saw changes than normal wood. With increased storage time, bark fell off at storage sites and hence the logs required no de-barking. The slippery surfaces of sprinkled logs caused no major handling problems but care was necessary in climbing on the sprinkled piles. It was suggested that the increased weight of stored logs increases transport costs. In the first years of selling logs from sprinkled areas, the same market price was obtained for fresh versus sprinkled logs but later the state forests gave a 20% reduction in price as compensation for direct costs (Delorme and Ripken, 1979). It was found that the entire timber output could be sold, and that there appeared to be a general demand for wet-stored logs.

The threat of market saturation was eased through exports of considerable quantities of timber to neighbouring countries, particularly to Scandinavia. Altogether 170 000 m³ of wet-stored logs were exported. Of special interest was the shipment of sprinkled spruce and pine from German forests to Japan. The moisture content and wood quality of one shipment were measured on departure and arrival at the destination (45-day voyage), (Peek, 1975). Under-deck storage provided minimum aeration and

maintained vapour saturation; pine logs with a minimum of 100% moisture content retained their quality throughout the voyage; logs above deck lost moisture and showed infection by blue-stain and red-stain fungi. It is recommended that deck logs be covered with a tarpaulin or sprinkled with sea-water to maintain moisture levels.

(8) *Economy of Sprinkler Storage*

Detailed data recording permitted evaluation and judgement of the economics of wet storage. Details can be found in Arnold *et al.* (1976), Kremser (1977, 1979a,b, 1980), Delorme and Ripken (1979). In considering results, it must be noted that the gale led to a catastrophic situation and the urgent need to salvage the timber. Neither human nor material resources, nor experience, were available to handle the 17 million m³ of windblown forest. Costs for the establishment and operation of the 93 storage sites are detailed in Table 1. The lowest and highest figures occurred in hilly terrain of the Harz mountains where storage was conducted under highly variable conditions. Average establishment costs of DM 15.7/m³ must be viewed in relation to an average market price for the stored timber of approximately DM 100/m³.

TABLE 1: ESTABLISHMENT COSTS FOR 93 SPRINKLER DEPOTS (DM/m³)*

	<i>min.</i>	<i>max.</i>	<i>ave.</i>	%
Site preparation	0.06	10.06	1.97	12.3
Technical installation	0.84	10.09	2.94	18.7
Log transport	1.00	14.08	7.21	45.9
Log piling	0.85	11.02	3.59	22.9
Total	8.93	26.04	15.71	100

*1 DM = 0.60 \$NZ

Operational costs for sprinkling and maintenance at the start in 1974 and in the fourth year, 1977, are summarised in Table 2. It is evident that with the passage of time storage costs decreased considerably from approximately 1 DM/m³ to approximately half this cost. Also notable is that the energy costs associated with the sprinkler system account for more than 50% of the total.

The State Forest Department of Lower Saxony has calculated the profit from wet storage of 1.39 million m³ of logs at 38 million DM, not allowing for innumerable invaluable side-effects such as the prevention of a price collapse, the maintenance of timber

TABLE 2: OPERATIONAL COSTS FOR 93 SPRINKLER DEPOTS (DM/m*) *

	1974	1977
Timber stored 000 m ³	1204	455
Log yard maintenance	0.14	0.03
Water and sprinkler system	0.37	0.18
Energy	0.46	0.25
Total	0.97	0.45

*1 DM = 0.60 \$NZ

supply and elimination of the need for insecticides and fungicides.

CONCLUSIONS

The wet storage of roundwood has proved to be a reliable method for the long-term protection of log quality. This is especially important when large quantities of wood must be handled because of catastrophic events such as gales. The method would also be useful for preserving timber after large fires or when great quantities are cut as a consequence of large-scale construction projects such as clearing dam sites. A critical factor in the past has been the lack of experience, the shortage of suitable equipment, and shortage of storage sites. The knowledge accumulated should shorten the leadtime required to establish water spray storage on a large scale. In Germany, wet storage has become part of log merchandising, permitting the central storage of wood for later selection and use without need for insecticides and fungicides with related environmental problems. Several of the storage sites described have been maintained through the years and are filled from time to time with freshly-felled logs to monitor storage experience.

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