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Standard Practice for Sampling Forest Trees for Determination of Clear Wood Properties[1]

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INTRODUCTION

The everyday use of wood for many different purposes creates a continual need for data on its mechanical properties. Small clear specimen testing to characterize a species has historically been employed for such property determination, and related methods of test are outlined in Methods D143.

Because wood is a biological material, its mechanical properties are subject to considerable natural variation. Thus, the results of tests to evaluate the mechanical properties of a species depend to a great extent upon how the forest trees are sampled for test material. Ideally, if the results of mechanical property evaluations are to be representative of the forest sampled, probability sampling of materials such as outlined in Practice E105 must be used. However, true probability sampling of the forest trees for determination of mechanical properties can be extremely complex and expensive because of the broad geographic range and topographic conditions under which a tree species grows. In some instances, direct probability sampling may be impractical, necessitating the need for alternative sampling procedures.[2, 3]

1. Scope

1.1 This practice offers two alternative physical sampling procedures: cruciform sampling and random sampling. The choice of procedure will depend upon the intended use for the test results, the resources available for sampling and testing, and the availability of existing data on the mechanical properties and specific gravity of the species of interest.

1.2 A third procedure, double sampling, is included primarily by reference. This procedure applies the results of cruciform or random samples through correlation to improve or update property values.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D143 Test Methods for Small Clear Specimens of Timber
D2555 Practice for Establishing Clear Wood Strength Values
E105 Practice for Probability Sampling of Materials

3. Significance and Use

3.1 This practice covers procedures of sampling for obtaining small clear wood specimens which, when tested in accordance with Methods D143 and, in conjunction with full-size product tests, will provide mechanical properties for use in deriving design properties for lumber, panels, poles, house logs, and other products.

[1] This practice is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.08 on Forests.

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[2] Bendtsen, B. A., Freese, F., and Ethington, R. L., "A Forest Sampling Method for Wood Strength," *Forest Products Journal*, Vol 20, No. 11, 1970, pp. 38–47.

[3] Pearson, R. G., and Williams, E. J., "A Review of Methods for Sampling of Timber," *Forest Products Journal*, Vol 8, No. 9, 1958, pp. 263–268.

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2 Data obtained by testing specimens sampled in accordance with these methods also provide information on the influence on mechanical properties of such factors as density, locality of growth, position in cross section, height in the tree, and moisture content.

3.3 Cruciform sampling is of principal value when information is desired on the influence on mechanical properties of height in the tree; of age or radial position in the tree; of rate of growth; the change from sapwood to heartwood; the relationships between mechanical properties and factors such as specific gravity; and making general comparisons between species for purposes of rating or selecting species for specific end-use products. Cruciform sampling does not provide unbiased estimates of mean values, percentile or other descriptive statistics, or a means of associating statistical confidence with estimates of descriptive statistics.

3.4 Double sampling is used when it is desired to improve or update existing estimates of mechanical property values that are the basis for establishing allowable design stresses for stress-graded lumber, plywood, poles and piling, and other wood products. The method involves predicting one property by carefully observing a well-correlated auxiliary property that is presumably easier or cheaper to measure. A sample estimate of the auxiliary property is obtained with a high degree of precision by representatively sampling the population. A smaller independent sample or a subsample of the large sample is used to establish a relationship between the auxiliary property and the property for which an estimate is desired. As applied to sampling a forest, double sampling has employed specific gravity to predict mechanical properties. The double-sampling method provides unbiased estimates of mean mechanical property values and an approximation method for estimating percentile values. Statistical confidence may be associated with the estimates of the means but not the percentile values.

3.5 Random sampling is used when probability estimates of descriptive statistics and property distributional characteristics are desired as the basis for establishing allowable design stresses for lumber and other stress-rated products. It is applicable when data for a species do not exist or when existing estimates are believed no longer applicable because of a changing forest character. Random sampling provides better probability estimates than double sampling and is less expensive and quicker if sampling and testing must be completed to establish mechanical property-specific gravity regressions for the double-sampling method.

4. Authentic Identification

4.1 The material shall be from trees selected in the forest by one qualified to identify the species and to select the trees. Where necessary, herbarium samples such as leaves, fruit, twigs, and bark shall be obtained to ensure positive identification.

5. Cruciform Sampling—Primary Method

5.1 The standard methods for preparing small clear specimens of timber, primary method, provide for cutting the log sections (divided into and identified as bolts) systematically into sticks of nominal 2½ by 2½ in. (63 by 63 mm) in cross section, that are later surfaced to provide the test specimens 2 by 2 in. ~~(50~~(52 by ~~50~~52 mm) in cross section, on which the system is based. These methods have served as a basis for the evaluation of the various mechanical and related physical properties of the clear wood of different species of wood. These methods have been extensively used, and a large amount of data based on them have been obtained and published.

5.1.1 The 2 by 2-in. ~~(50~~(52 by ~~50-mm)~~52-mm) test specimen has the advantage that it embraces a number of growth rings, is less influenced by earlywood and latewood differences than smaller specimens, and is large enough to represent a considerable proportion of the material.

5.1.2 The choice of specimen size may be influenced by the objectives of sampling and by the rate of growth of the material. Radial property gradients are primarily influenced by age, and large specimens that encompass several rings may mask the age influence. Height gradients must be evaluated by specimens from the same annual ring because of age influence. Thus, small specimens are preferred for measuring both radial and height gradients. When the purpose of sampling is to estimate clear wood properties, large specimens that include a number of annual rings are preferred. Even with 2 by 2-in. ~~(50~~(52 by ~~50-mm)~~52-mm) specimens, fast rates of growth will result in few rings per specimen. Regardless of the purpose of sampling, the analysis and reporting of data may require careful consideration of the character of the specimen.

5.2 *Selection of Number of Trees*—For each species to be tested, select the number and the character of the trees to accomplish the purpose of the sampling. For traditional mechanical property data base development, a minimum of five trees have usually been selected that have been judged "representative" of the trees harvested of the species. Note that if unbiased estimates and statistical confidence statements are required, other methods are needed (Section 3).

5.3 *Selection and Number of Bolts*—The material of each species selected for test shall be representative of the clear, straight-grained wood in the merchantable bole of the tree. A traditional method of selection is shown in Appendix X2. Note that the sampling permits varying the intensity of sampling by tree (in accordance with Appendix X2~~A2)~~) if the resulting data will support the anticipated analysis. X2.1 illustrates merchantable section and bolt labeling.

5.4 *Substitution of Flitches for Bolts:*

5.4.1 In cases where the logs or bolts are over 60 in. (1.5 m) in diameter, a single flitch 6 in. ~~(150 mm)~~(15 cm) in thickness, taken through the pith representing the full diameter of the log, may be substituted, in the same length, for the full log or bolt specified in 5.3.

5.4.2 Where orientation of test specimen to geographic features is considered critical, flitch shall maintain the coordinates regarded as important in the specimen of 5.9.

5.5 *Selection for Site Representation*—Inferences in analysis that relate to geographic distribution or site-specific features must be anticipated in selecting both the sample numbers and sources. The number of trees shall conform to 5.2 and 5.3. If the analysis requires statistical inferences, random sampling (Section 7) is one method.

5.6 *Field Marking:*

5.6.1 Field marking procedures shall ensure identification of trees, bolts, and shipment. Appendix X2 provides a traditional method.

5.6.2 If the orientation of test specimens to geographical or bolt features is critical, maintenance of cardinal point orientation is recommended.

5.7 *Field Descriptions:*

5.7.1 Complete field notes describing the material shall be fully and carefully made by the collector. These notes shall be sufficient to supply documentation similar to that in Table X1.1, with actual content chosen as appropriate for the objectives of the study.

5.7.2 Photographs of the standing trees selected should be taken when practicable.

5.8 *Preparation for Shipment*—Maintenance of moisture content of the material and of all labeling documentation is a requirement. Paragraph X2.3 provides traditional guidelines.

5.9 *Sawing and Marking of Bolts and Test Sticks*—Sections of logs (consisting of two bolts) shall be marked and sawn into 2½ by 2½-in. ~~(60~~(63 by ~~60-mm)~~63-mm) sticks. Marking of bolts and sticks shall maintain continuity to the tree, and shipment. Consistency with 5.6 shall be maintained. ~~Paragraphs A2.1~~Sections X2.1through ~~A2.4~~X2.4 document the traditional procedures.

5.10 *Matching for Tests of Dry Material:*

5.10.1 If one purpose of sampling is to provide comparison of green and dry properties, provisions may be made for matching of specimens within the tree. The traditional approach is as follows:

5.10.2 The collection of the material (Section 5) has been arranged to provide for tests of both green and dry specimens that are closely matched by selection from adjacent parts of the same tree. The 8-ft (2.4-m) long sections, after being marked in accordance with 5.9, shall be sawn and marked in 2½ by 2½-in. ~~(60~~(63 by ~~60-mm)~~63-mm) by 8-ft sticks. Each 2½ by 2½-in. by 8-ft stick shall then be cut into two 4-ft (1.2-m) pieces, making sure that each part carries the proper designation and bolt letter.

5.10.3 Some of the 2½ by 2½-in. by 4-ft ~~(60~~(63 by ~~60-mm~~63-mm by 1.2-m) sticks from each 8-ft (2.4-m) section are to provide specimens to be tested green (unseasoned) and the remaining ones are to be dried and tested. To afford matching, the 4-ft sticks of one bolt shall be interchanged with the 4-ft sticks of the next adjacent bolt from the same tree to form two composite bolts, each being complete and being made of equal portions of the adjacent 4-ft bolts. The sticks from one of these composite bolts shall be tested green and those from the other shall be tested after drying. Thus, the sticks of each composite bolt shall be regarded as if they were from the same bolt. Paragraph X2.5 illustrates a method of forming composite bolts.

5.10.4 The traditional procedure provides for end-to-end matching (end matching) of sticks to be tested dry with those to be tested green, which is to be preferred when practicable. If, because of the nature of the material, end matching is not practicable, side matching may be used.

6. Cruciform Sampling—Secondary Method

6.1 The cruciform secondary method is intended for use in evaluating the properties of wood only when relatively small trees, generally less than 12 in. ~~(300 mm) in diameter,~~ (30 cm) in diameter when measured approximately 4½ -ft (1.37-m), diameter breast height, are available to provide the test specimens and only when such trees because of crook, cross grain, knots, or other defects are of such quality that the longer clear, straight-grained specimens required by the primary method cannot reasonably be obtained. Whenever possible, the procedure for the primary method shall be used regardless of the size of trees. Since the procedure for the secondary method for many features, such as in selection and care of material, is identical with the primary method, the secondary method presented herewith are referenced to the primary method, and procedure is given only where it differs therefrom. For convenience the section numbers in the secondary method corresponds in the last two digits with the numbering of the primary method. Thus, Section 6 for the secondary method corresponds in subject matter to Section 5.

6.1.1 Because of the cross-sectional size and the length of specimen required for some of the tests (30 in. ~~(760 mm)~~(76 cm) for static and impact bending) it is, however, sometimes difficult to obtain test specimens in adequate number and entirely free of defects from bolts representing smaller trees, particularly trees under 12 to 15 in. (30 to 38 cm) in diameter. With increasing need for evaluating the properties of species involving smaller trees, and the increasing importance of second-growth timber that is expected to be harvested much before it reaches the sizes attained in virgin stands, there has developed a need for secondary methods of test in which at least the longer test specimens are smaller than 2 by 2 in. ~~(50~~(52 by ~~50~~52 mm) in cross section.

6.1.2 The exceedingly rapid rate of growth and corresponding wide annual rings in much second-growth material, together with the desirability of incorporating more than a single year's growth increment in a test specimen, has necessitated limiting the minimum cross section of test piece in these secondary methods to 1 by 1 in. ~~(25~~(2.5 by ~~25 mm).~~2.5 cm). Data analysis based on these small specimens of rapid growth rate wood is particularly vulnerable if the purpose of the sampling is to estimate total clearwood properties. See additional comments in 5.1.2.

6.2 *Selection and Number of Trees*—For each species to be tested, at least ten trees representative of the species shall be selected.

6.3 *Selection and Number of Bolts:*

6.3.1 See 5.3~~5.3.1,~~, noting that, if using ~~A2.1.1~~X2.1.1 as a guide, the minimum number of trees is increased to ten. If information on variation with height is desired, use of two trees is recommended *for that purpose* in this secondary method.

6.3.2 From the trees not used for study of variation with height, take the 8-ft (2.4-m) section (c-d bolts) next above the 8-ft butt log if this section falls within the merchantable length of the tree; otherwise, take the 8-ft section comprising the two highest standard bolts (multiples of 4 ft (1.2 m)) within the merchantable length.

6.4 *Substitution of Flitches for Bolts*—For the small trees to which this secondary method is applicable, bolts representing the full diameter of the log are required, and flitches shall not be substituted for bolts.

6.5 *Selection for Important Species*—For important species of wide geographical distribution, test material shall be selected from two or more localities or sites. The number of trees of a species selected from each site or locality and within tree sampling shall conform to the requirements of 6.2 and 6.3.

6.6 *Field Marking*—See 5.6.

6.7 *Field Descriptions*—See 5.7.

6.8 *Preparation for Shipment*—See 5.8.

6.9 *Sawing and Marking of Bolts and Test Sticks*—All bolts shall be marked on the top end into 2½-in. ~~(60-mm)~~(63-mm) or 1¼-in. ~~(30 by 30-mm)~~ (32-mm) squares as shown in Fig. 1, and sawed into nominal 2½ or 1¼-in. sticks. X2.6 may be used for guidance.

6.10 *Matching for Tests of Dry Material:*

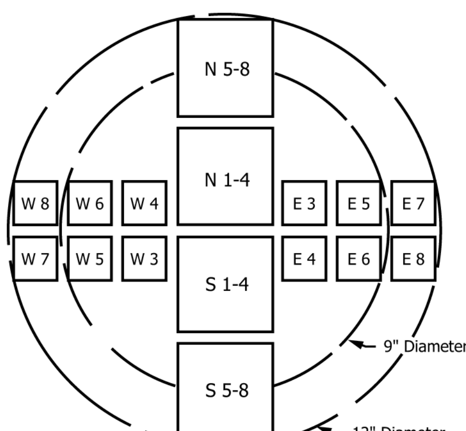
6.10.1 If one purpose of sampling is to provide comparison of green and dry properties, provisions may be made for matching of specimens within the tree. The following sections relate the traditional approach.

6.10.2 The collection of material has been arranged to provide for tests of both green and dry specimens that are closely matched by selection from adjacent parts of the same tree. The 8-ft (2.4-m) long sections, after being marked in accordance with 6.9, shall be sawed into 2½ by 2½-in. ~~(60~~(63 by ~~60-mm)~~63-mm) or 1¼ by 1¼-in. ~~(30~~(32 by ~~30-mm)~~32-mm) by 8-ft (2.4-m) sticks, and numbered and lettered in accordance with 6.9. Each 8-ft stick shall then be cut into two 4-ft (1.2-m) pieces, making sure that each part carries the proper designation and bolt letter. If the 8-ft section is not straight, it may be found more desirable to cut it into 4-ft lengths before cutting the 2½ or 1¼-in. square pieces. If this is done, care shall be taken to secure end-matched sticks in the two 4-ft bolts and to ensure that each part carries the proper designation and bolt letter.

6.10.3 Composite bolts shall be formed in accordance with the principles of 5.10.3 and 5.10.4. Section X2.7 may be used for guidance.

7. Random Sampling

7.1 The general principles of probability sampling of materials (Practice E105), including setting sample size, collecting sample material in an objective way, and data analysis, apply to sampling the forest trees for determination of mechanical properties.



NOTE 1—Sticks cut from the *N-S* axis shall be 2½ by 2½ in. ~~(60~~(63 by ~~60~~63 mm) when green. Sticks cut from the *E-W* axis shall be 1¼ by 1¼ in. ~~(30~~(32 by ~~30~~32 mm) when green.

FIG. 1 Sketch Showing Method of Cutting Up the Bolt and Marking the Sticks for the Secondary Methods

Generally, sample size is dictated by the precision desired in the property estimates. Sampling the forest trees for determination of mechanical properties, however, presents unique problems in maintaining objectivity in sampling because the sample population, for practical purposes, is essentially infinitely large, and because of problems associated with broad geographic ranges and inaccessible topography.[2] The number of locations, their growth conditions, and the trees per location enter the picture also. For a given sample size, one sample per tree probably provides the most precision. However, if the cost of selecting a tree, and finding, cutting, and bringing it out of the woods is high, then it may be more economical to sample fewer trees but more intensively within a tree or within a location, reflecting the need to increase the total numbers of specimens tested to achieve the same precision. Thus, if it is desired to do a sampling experiment as economically as possible, the sample size depends not only on the precision of estimates desired but also on within and between tree variation, within and between location variation, and the cost of sampling versus the cost of testing individual samples. The experimental design should seek the optimum combination of sampling intensity at each stage of sampling.

7.1.1 The principles of random sampling can be followed although actual sampling procedures may differ. Details will vary according to objectives and the physical nature of the sampling. Appendix X1 provides an example which approximates the methods used in North America for some of the entries in Method D2555. Important aspects of the statistics when designing a random sampling procedure are covered, with specific discussions of procedures used in Australia and England.

7.2 Many of the principles of the cruciform method (identification in Section 4; field marking, descriptions, preparation for shipment, sawing and marking of sticks, dry/green matching in Section 5) provide guidance for orderly preparation of specimens when following the random sampling methods.

8. Double Sampling

8.1 Specific gravity has been the independent variable traditionally employed to predict mechanical properties through double sampling. A reliable estimate of the mean specific gravity for a species is obtained by intensively sampling the forest population of a species. This value is substituted into regression equations to obtain estimates of mean mechanical property values. The regression equations, relating mechanical properties and specific gravity, are generally calculated from existing data sets, see Sections 5 and 7 and Methods D143, in which specific gravity and the mechanical property were measured on the same specimen, although in some instances supplemental sampling and testing may be needed to establish reliable regression. Paragraph 4.1.4.2 of Method D2555 suggests that a correlation coefficient of at least 0.50 is desirable to provide satisfactory property estimates by double sampling. Method D2555, Section 4.1, presents a thorough treatise on the double sampling method.

9. Keywords

9.1 clear wood; forest; forest trees; sampling

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF AN APPROPRIATE RANDOM SAMPLING PROCEDURE

X1.1 *Sample Observational Unit*—The cross section of a standard strength specimen (primary method) is 2 in. ~~(50~~(52 mm) square, and the length may vary from 6 to 30 in. ~~(150~~(15 to ~~760 mm),~~76 cm), depending upon the particular test involved (Methods D143). Thus, the sampling unit is a 2-in.-square stick of wood long enough to supply one test specimen of each type to be evaluated. For example, if static bending, compression parallel-to-grain, compression perpendicular-to-grain, shear, and hardness characteristics of a timber species are to be evaluated, specimen lengths of 30, 8, 6, 2½~~, and 6 in. (760, 200, 150, 60, and 150 mm),~~ in. (76, 20, 15, and 6 cm), respectively, are required or a total length of actual material of 52½ in. ~~(1320 mm).~~(133 cm). Allowing extra material for machining waste, annual ring orientation, and the elimination of growth defects, the sample unit is a stick about 2½ by 2½ in. ~~(60~~(63 by ~~60~~63 mm) in cross section and perhaps 5 ft (1.5 m) long, the actual length depending upon the quality of the material. If the properties are to be evaluated in both a green and a dry condition, the sample unit would be a pair of such sticks.

X1.2 *Population*—The sample population in the example could be defined as all possible 2½ by 2½-in. by 5-ft (63 by 63 mm by 1.52 m) clear, straight-grained sticks that can be cut from all trees in all stands of the species of interest. However, "all trees" may not necessarily be the population of interest. For example, if the purpose of a sampling experiment is to develop estimates of mechanical properties as a basis for design stress for structural lumber, the trees of interest may be limited to those of sawtimber size. The population for sampling might then be defined as all possible 2½-in. square by 5-ft long sticks that can be cut from sawtimber-sized trees in stands that can be harvested now or in the near future by contemporary logging techniques.

X1.3 *Random Selection*—A method is outlined in this section for collecting a random sample of *n* observations of a species. The procedure involves several stages in which selection is made at each stage, with probability approximately proportional to volume (ppv). This means, for example, that a region having a high volume of timber has a greater chance of being selected than a region of lower volume. Likewise, large trees or large bolts have greater probability of selection than smaller ones. The example assumes that detailed estimates of timber volume are available for the development of the sampling plan. If timber volume estimates are not available, some other system must be used to ensure objectivity or representativeness in sampling.

X1.3.1 *Selection of Areas*—To select areas to be sampled, timber volume estimates are tabulated for the species by the smallest area unit for which volume information is available throughout the growth range of the species. Then *n* areas, the number of test species desired, are selected with ppv. Selection is with replacement, that is, the same area can be selected more than once. To illustrate the selection of areas with ppv, consider the five example area volumes of Table X1.1. Five areas with volumes and cumulative volumes are available, and the sample size *n* is six.

X1.3.1.1 From a table of random numbers, six numbers from one through the cumulative volume total 26 320 are drawn. Each random number identifies an area to be sampled. If a random number is equal to or smaller than the cumulative volume of area *x* but larger than the cumulative volume of the preceding area, then an observation from area *x* is included in the sample. To illustrate, six random numbers and the corresponding areas (in parentheses) might be: 19 162 (C), 26 263 (E), 6682 (B), 1785 (B), 3879 (B), and 8253 (B). It is noted that in the United States areas for which volume estimates are available may number in the thousands, and the probability is small that the same area will be drawn more than once, even for large sample sizes.

X1.3.2 *Selection of Location*—For each area thus selected, sampling locations are randomly drawn by any convenient scheme. This can be done by placing a numbered grid over a map or by assigning numbers to townships, sections, or quarter sections and then selecting numbers at random. Grid intersections or quarter corners can arbitrarily be designated as the sampling location or plot. Another technique is to simply draw random pairs of coordinates to the nearest minute, ½ minute, or whatever resolution is desired. This will depend upon sampling conditions. In some areas, particularly in rugged terrain, a field technician may have considerable difficulty precisely locating the sampling location on the ground. Therefore the researcher may decide that a sampling grid finer than one or two miles (km) is not practical and that significant bias will not be introduced in the experiment with this size grid. Selecting grid intersections or paired coordinates at random with equal probability shifts the sampling scheme from selection with ppv to volume to probability proportional to area. If the distribution of the timber is uniform throughout an area, the two systems are comparable. This is usually not the case, however, and selection in proportion to area tends to disproportionately favor the units in thin or peripheral stands. This is the reason the smallest areas for which volume estimates are available are used. This tends to minimize the sampling error because smaller areas tend to have more uniform timber volume distribution.

X1.3.3 *Selection of Tree*—To select a tree from each location, a sample plot center is first objectively located or defined. One means is for the field technician to locate the sampling location as accurately as possible with reference to the selected coordinates and then move a preselected distance (perhaps 200 yd (180 m)) on a random azimuth. The new location is then the plot center. From the plot, a tree is then randomly selected with ppv volume, using a basal area prism (a 3.03-diopter prism has proven successful for this purpose). Standing on the plot center and starting with a north sighting (or any other preselected or randomly selected azimuth) and turning clockwise, the first qualifying tree is selected that, when viewed at breast height through the prism, overlaps any part of the view seen above the prism. Trees are rejected if they do not meet minimum diameter requirements defined by the experimental plan.

X1.3.4 *Selection of Bolt*—The selected tree is felled and bolts of length equal to the observational unit are marked off up to a minimum top diameter defined in the experiment. A 6-in. ~~(150-mm)~~(15-cm) diameter is probably the minimum practical diameter for obtaining a 2½-in. (63 mm) square stick located to one side of the pith. The diameter is measured at the upper end of each bolt, the diameters are squared, and a single bolt is randomly selected with probability proportional to squared diameters

TABLE X1.1 Area Volumes for Illustration of Selection of Sample Areas With PPV

Area	Volume, 1000 ft^3	Cumulative volume, 1000 ft^3
A	350	350
B	14 070	14 420
C	4970	19 390
D	840	20 230
E	6090	26 320