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WATERSHED MANAGEMENT RESEARCH MEETING

Manitou Experimental Forest

May 6-10, 1957

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Fort Collins, Colorado

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FOREWORD

Following are the notes of the discussions at our Watershed Management Research Meeting at Manitou. I hope these notes will serve as a refresher of the meeting and be helpful to you in your research work. The notes will also be helpful to others not in attendance at the meeting.

As I mentioned to you we could have had any one of several types of meetings. For example, we could have reviewed individual projects and studies to ascertain their adequacy as was done in our Range Management Research Meeting 2 years ago. Also we could have had a field trip, capped with a seminar, on a specific aspect of our work as we did in Forest Management Research last summer. But because our watershed management research staff is relatively new and expanding and we need to know each other better, we decided that it would be profitable to make our Manitou meeting an informal but searching discussion of the various measurements and processes involved in watershed management research. We appreciated that some of the discussion might appear to some to be elementary. This was deliberate, since we wanted to pick the brains, so to speak, of the older staff members for the benefit of the new ones. In other words, we desired to share our knowledge and experiences for the benefit of our expanding watershed management research team. Personally, I feel that our objective was accomplished and I trust it will be helpful to you all.

One last point: As I also mentioned to you at Manitou, the real purpose of our research is to obtain and impart through appropriate publications helpful and usable information concerning watershed management. It is good to be skilled in watershed management research measurements and processes, and we must be skilled in these aspects to do our job effectively. But unless we make available our research information, our skills are of little consequence. So, with our Manitou discussion meeting as a background, I encourage you to pursue your research with confidence and enthusiasm and to make it a point to make available your research results currently in a sound but understandable and meaningful manner.

Raymond Price

RAYMOND PRICE, Director

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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This meeting was planned to allow a review of the measurements and processes involved in watershed research. The agenda lists topics and discussion leaders. The discussion should come from all those present. We are fortunate to have with us Bernie Frank, Ted Osborne, and Hank Sims from the Washington Office; George Hardaway and Alan Lamb from Region 3; and Jack McNutt from Region 2. We'll expect to hear from them throughout the meeting.

As we move along, I expect we'll find that watershed research depends on an extremely broad foundation of numerous specialties. None of us can know enough in each specialty but we must know something about them all. Also we'll find that there are many more things that the specialists need to know about their own fields. A major purpose of this meeting is to find out what we do know and perhaps most important discover what we need to know. Perhaps some will be discouraged by how much is yet to be discovered. I hope not because the unknown is the challenge and stimulus to research. By becoming aware of ignorance, we are stimulated to learn.

Watershed management is not a new concept. The beginning of scientific forestry in the United States and the establishment of the national forest system was based on a recognition that watershed management was needed. In Europe, forests have been managed to protect watershed lands for hundreds of years. Watershed management research, however, is not ancient. The first reported studies and experiments to test the relation between forests and water are hardly 50 years old. Much of the earlier work was planned more for demonstration than the acquisition of new knowledge. The protection of watersheds has sometimes been the basis for forestry practices, desirable in themselves, only remotely connected with floods or water supply.

The long history of watershed management and the acrimonious, if ancient, debate with engineers have introduced some wishful ideas into the bedrock of solid fact. During our seminar, let's try to separate what we think we know from what is known to provide a solid support for future work.

(M. D. Hoover)

WEATHER FACTORS

M. Martinelli, Jr.

I. Need for meteorological measurements in watershed research

A. Historic climatological records to compare:
(1) one year, decade, or century with another
(2) one place with another
(3) probably should follow Weather Bureau methods for these data

B. To furnish independent variables for specific studies:
(1) Special instrumentation will be needed here.

C. Which work centers or projects should undertake the collection of historic records it seems to me would depend on:
(1) Length of proposed work in the area
(a) Long-term projects - probably will want such records
(b) Medium-term projects - doubtful
(c) Short-term projects - probably not want such records

D. Discussion
(1) Type of records taken should be tied in with purpose of project
(a) Standard Weather Bureau records an essential for characterizing regional climates.
(b) Research should try to collect the specific information necessary for the project in question (for example, soil surface temperatures associated with failure of certain types of reproduction).

(2) There may be a possibility of extending weather data taken at a nearby permanent weather station to a project area by maintaining a weather station at the study area for a relatively short while.

(3) Much of the existing weather data has not been compiled nor analyzed to see how useful it really is.

(4) As a project is developing, weather data being taken should be compiled, analyzed, and examined as to its purpose and contribution to the project.

(5) This analysis should be careful to determine if proper variables are being taken and at the proper place.

(6) Any records taken should be taken conscientiously and accurately.

II. Methods for measuring

A. Air temperatures

(1) Types of measuring devices commonly used by Weather Bureau

(a) Nonrecording

1. Liquid in glass (mercury / alcohol)
2. Bimetallic temperature sensing element with a dial to indicate current, maximum, and minimum temperatures.
3. Electrical resistance units

(b) Recording

1. Bourdon tube - thermograph (hygrothermograph)
2. Electrical resistance

(2) Temperatures commonly taken (W.B.)

Maximum (liquid in glass)
Minimum (liquid in glass)
Wet bulb and dry bulb (liquid in glass)

Current temperature should be read from maximum thermometer after resetting, or from dry bulb of the psychrometer set.

(3) Shelters for thermometers

Weather Bureau medium sized louvered shelter most common.
Shelter should not be closer than twice (or preferably four times) the height of the obstruction.
Should be at least 100 feet from extensive areas of concrete or paving.
Shelter should be 4 feet from ground and facing north.

(4) Supports (liquid in glass)

Townsend support for maximum and minimum put on the horizontal crossbar in the shelter.

(5) Other types of temperature measuring devices

(a) Thermistors

These are thermally sensitive resistors for the detection, measurement, and control of physical energy.

These semiconductors increase in resistance as temperatures decrease. (Negative temperature coefficient.)

Made from manganese, nickel, and cobalt oxides in batch lots.
Usual shapes are rods, washers, or discs.

II. Methods for measuring air temperatures (continued)

(a) Thermistors (continued)

Variations in temperatures can be detected and transmitted automatically from distant points either by wires or by radio.

(b) Pyrometers -- thermocouples and optical

Thermocouples-- bimetallic units of various sizes which develop an electric current when heated differentially-- one end hot, the other cool or cold.
Can be hooked to resistance meters to give a measure of temperatures. Usual application is for very high temperatures.

Optical -- Peer at any hot object; then control heat to a filament and match color of filament and hot object. Can read temperature on galvanometer.

(c) Melting devices

Pellets - about size of aspirin

Colored crayons -- all melt at specific temperatures from 125° to 1600° F. within accuracy of 1 percent.

Methods for measuring

B. Soil temperatures (See Geiger, p. 131)

Surface temperatures:

Mercury thermometers placed on the surface measured only the lowest layer of air.

Mercury thermometers placed just under the soil give only the temperature close beneath the surface.

Very tiny thermocouples can be used most satisfactorily. Insert a glass tube into the ground, then touch tube wall with thermocouple to get temperatures at surface, in air above, or in soil below. Very satisfactory results.

II. Methods for measuring soil temperatures (continued)

Other ways to get soil surface temperatures

(1) Get temperature gradients in air and in soil; then extrapolate to get the soil surface temperature.

(2) Measure radiation temperatures from ground and compute temperatures. Can use parabolic reflectors to concentrate radiation for easier measurement.

(3) Flatiron method:-- Insert bulb of mercury thermometer in copper plate (1-1/2 sq. cm.). Insulate plate on top with felt. Move "flatiron" over surface to get temperature. This integrates temperatures for the 1-1/2 sq. cm. area, but is best way to use mercury thermometer.

(4) Controlled melting materials -- heat tabs, pencils, and liquids.

Methods for measuring

C. Wind -- measured in terms of the velocity which is a vector including speed and angle with respect to horizontal.

(1) Direction -- in reference to true north. It is the direction from which the wind comes. Expressed to 16 points of compass or to nearest 10 degrees.

Instruments -- 30 to 35 feet aboveground on tower. Free exposure - level terrain - free from obstructions to wind. Instruments should not be within 10 times the height of the obstruction.
Compromise -- have instrument at least as high as anything within 100 feet to 200 feet and 12 feet higher than anything within 100 feet.

(2) Speed

Generally a 1-minute average. May also be 5-minute average. Weather Bureau uses knots rather than m.p.h.

Instruments:-- 3- and 4-cup anemometers, hemispherical and conical cups. Also one type uses a propeller (Windial). Most have 1 and 1/10 mile contacts. Some have a d.c. generating unit.

Other types of instruments to measure speed:

Pendulum -- either free swinging or spring loaded.

Manometers -- Pitot tube idea used in studies of sand movement.

Electrically heated wire -- experimental purposes (most accurate now in use)

Methods for measuring

D. Humidity

Common methods: Chemical absorption
Wet-dry bulb thermometers
Hygroscopic expansion
Temperature of condensation

Other methods: Pan hygrometer
Spectroscope
Electric resistance

Sling psychrometer used to get relative humidity and dewpoint. These are always expressed in regard to water (W.B.). When ice forms on sock, readings from W. B. Circular 235 give values in regard to ice. Must convert.

Hair hygrometer (hygroscopic expansion)
Calibrated to read relative humidity directly.
Continuous records.
Accuracy of the hair elements may be poor and calibration is very difficult, especially in field.

Suggestions for operating hygrothermographs: (from Co-op. Snow Investigations Report No. 2)

(1) Shelter -- Should give free ventilation; hygrothermograph should be on shelf 6 inches off floor of shelter. Cotton belt type too small. W. B. large shelter recommended. We need a better shelter to give protection from blowing snow on exposed sites.

(2) Handling -- Use extreme care to avoid jarring or straining elements. Keep hands off the hair elements.

Methods for measuring humidity (continued)

Suggestions for operating hygrothermographs (continued)

(3) Shipping-- Tie slack in the hair element. Loosely tie pens to pen release arm to prevent swinging out but permit vertical movement.
Tape chart clip to floor.
Wrap clock separately.

(4) Starting clock.-- Rotate clock counter-clockwise until gears are tight; set time and release.

(5) Be sure plate on bottom of clock is set to prevent gears from bending. Three screws to loosen for this adjustment.

Dewpoint instruments

(1) Lithium chloride units.-- Pick up H_2O from air

Foxboro Dewcel-- 50° F. to 140° F., but doesn't get very low R.H. at any temperature (< 10 percent) (approx.$400 with recorder).

(2) Temperature of condensation methods

(a) Alnor dewpointer -- nonrecording; uses pressure differential to cool air.

(b) Ether dewpointers -- cool air by evaporating ether

Recording humidity instruments

(a) Telepsychrometer.-- Two resistance thermometers-- one dry, one kept wet.
Records each minute: dry bulb temperature and depression of wet bulb

Methods for measuring

E. Evaporation

(1) Weather Bureau has maintained special stations to measure evaporation from a free H_2O surface since about 1910.

(2) Usually use hook gage to read level of H_2O in small galvanized pans at regular intervals. Allowance is made for water added by precipitation.

(3) Coefficients have been developed to translate evaporation data as read at the pans to large bodies of free water such as lakes, ponds, and reservoirs.

Methods of measuring evaporation (continued)

(4) Weather Bureau Circular B covers details of instrumentation and installation at evaporation stations

(5) Usual instruments at evaporation stations are:

(a) Anemometer - cups 6 inches above pan rim

(b) Instrument shelter
1. Maximum-minimum thermometers
2. Wet-dry bulb thermometers and fan

(c) Nonrecording 8-inch rain gage
(d) Recording rain gage (optional)
(e) Maximum and minimum temperatures of H_2O 1/4 inch below water surface (either floating thermometer or temperature sensing elements and recorders)
(f) Pan and hook gage
(g) Hygrothermographs are replacing psychrometers at many of the stations
(h) Fence around whole area

(6) Types of evaporation pans in use (not necessarily complete)

(a) Bureau of Plant Industry pan (cylindrical)
First in general use
6 feet x 24 inches, set 20 inches into ground
Water level at ground level
Ratio $\frac{\text{lake}}{\text{pan}} = 0.94$.

(b) Young screen pan (cylindrical)
2 feet x 3 feet deep, 33 inches into ground
H_2O kept at ground level
1/4 inch mesh screen suspended one-half way between pan rim and H_2O surface
Ratio $\frac{\text{lake}}{\text{pan}} = 0.98$.

(c) Weather Bureau pan (cylindrical)
4 feet x 10 inches mounted on 2 x 4's to let air circulate below it
7 inches to 8 inches of H_2O in pan
Ratio $\frac{\text{lake}}{\text{pan}} = 0.77$.

(d) Square ground pan (Colorado pan)
3 feet x 3 feet x 18 inches deep, set 14 inches into ground
H_2O kept at ground level
Ratio $\frac{\text{lake}}{\text{pan}} = 0.89$

F. Discussion

(1) Turbulence may be an important feature of the wind and it is seldom measured.

(2) There are two ways that turbulence may be studied: One is the use of motion pictures and smoke generators. The other is suggested in a Japanese article concerning sea fog-- a translation of this will be distributed soon from the director's office.

(3) It may be well to standardize weather records. If this is done it may be well to tie in with the fire research people rather than the Weather Bureau systems.

(4) Consideration should be given to analyzing wind data in light of some of the concepts mentioned by Ives (AGU Vol. No. 3, p. 478) and the references he gives.

III. Usefulness of information not ordinarily obtained

A. Solar radiation

(1) The most independent of the climatic factors (Kittridge)

(2) Differences in the following are caused directly or indirectly by radiation:

(a) Temperature (c) Evaporation
(b) Humidity (d) Transpiration

(3) Essential to the study of heat balances for snow work especially.

(4) Depending on needs, it can be developed into radiation for

a. All wave lengths, either net or incoming
b. For selective wave lengths
c. For scattered radiation from sky
By using hemispherical and perpendicular recorders

B. Condensation

Again very important in any type of heat balance study, such as snow. The heat released can be considerable.

Under certain conditions the water accumulated may be appreciable. (Coshocton, Ohio, reports from 4 inches to 6 inches per year.)

Usefulness of information not ordinarily obtained (continued)

C. Wind direction

Usually a climatological factor, just to describe weather conditions more completely.

For studies concerned with either wind drift phenomena or with wind shelter, this would be as important as wind speed.

D. Extra data to determine air mass type

The key factor not usually taken is cloud cover.
This has very pronounced influence on radiation effects.
In hilly country on cloudy days the difference in radiation on different slopes (aspects) is very small since it is from diffused radiation.
On clear days, radiation varies greatly on north and south slopes.

Brooks and Kelly (AGU Vol. 32, No. 6, Dec. 1951) suggest this as one component of a simple observational system of classifying air masses for better definition of weather conditions.

E. Wind gustiness

Not generally measured except as in general terms

Again of most importance for wind drift or wind shelter studies

The gusts may be the important factor in moving both dirt and snow since it is necessary to get at least some of the particles into saltation before the general movement of particles starts.

F. Atmospheric pressure

Of primary importance to forecasting units.

Major improvements for watershed management would probably be to anticipate periods of heavy precipitation and/or runoff to permit on-the-ground observation and/or measurements.

IV. Considerations for future programs

A. Should consider whether data are for a historical climatological record or for obtaining independent variables for more exact correlations.

Considerations for future programs (continued)

B. In case of climatological data

C. F. Brooks (AGU Vol. 28, No. 6, Dec. 1947) recommends taking (1) temperature, (2) precipitation, (3) wind, (4) cloud cover, (5) local storms.

Net work of stations may be open for (1) insolation, (2) daily maximum temperature, (3) precipitation, (4) wind, (5) visibility.

Net work of stations should be less open for (1) daily minimum temperatures, (2) snowfall, (3) four or five stations in different types of topography for each 500 square miles.

C. If an attempt is being made to correlate some factor or factors with specific weather features, then special and specific data are needed which will fit the problem.

D. There is a possibility for using temporary stations and climatic profiling in conjunction with permanent stations to reduce the number of permanent stations. (Brooks, C.F. AGU Vol. 28, No. 6.)

This requires good maps and charts to permit complete expansion of data.

E. Use of air mass to more completely describe conditions.

Better correlations of weather data and more complete and meaningful descriptions of existing conditions are possible if days are classified by air mass types. The lumping into air mass types seems to reduce the variability of weather data. It serves to stratify the data. (Brooks and Kelly. AGU, Vol. 32, No. 6.)

F. Kytoons may be useful to take data from within the tree crown zone and above. This captive balloon has many features of a kite. Can take a simplified radiosonde aloft to get temperaturesand humidities. Transmits impulses down cord and picked up by phonograph crystal pickup system. (Neuberger - AGU Vol. 30, No. 1.)

G. Possible to get help from some outside agencies such as the major airlines.

H. Discussions

(1) Might be desirable to stratify weather factors on the basis of some natural breakdown such as air mass.

Considerations for future programs (continued)

H. Discussions (continued)

(2) It has been found that where there are two correlated variables it is often possible to make them independent for statistical purposes by using differences between the measurements. For example, soil temperatures and air temperatures are correlated, but air temperature and the difference between air temperatures and soil temperatures can be used as independent variables in a regression.

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MEASUREMENT OF PRECIPITATION

Jerome S. Horton

In most watershed studies, precipitation measurements are needed. Measurement of precipitation over any appreciable area creates many problems which can be grouped into three classes:

1. Kind of gages to use
2. How many gages to use
3. Where to put them

Kind of gages

Weather Bureau standard gage, 8 inches in diameter, and installed vertically, has been used for almost all measurements of precipitation and should continue as the standard for measurement of total rainfall in flat or rolling country.

A standard Weather Bureau gage tilted normal to the average slope to be measured has been critically studied on the San Dimas Experimental Forest in California. In one study 19 percent more rain was caught in a watershed by using tilted gages. These gages have been demonstrated as giving a more accurate measurement of the rain actually falling on the slope than a vertical gage (Hamilton - "Rainfall sampling on rugged terrain." USDA Tech. Bul. 1096.)

The group in general accepted the tilt gage as superior in topography which slopes toward the direction of the prevailing winds during major storms. A question came up as to how steep a slope should be before tilt gages are recommended. No definite answer is available because the work on the San Dimas Experimental Forest was done on steep slopes only. After some discussion, 25 percent was suggested as a possible demarcating gradient. Also if the bulk of precipitation comes as small storms, use of the tilted gages would be questioned.

Stereo funnels can be used instead of tilting the gage, with the same results. This is essential for placing recording rain gages on a tilt basis.

Storage gages are essential for snow measurement at sites which are hard to reach. There appears to be no very good methods to measure incoming snow. Need to have more field observations during snow storms in order to devise better means of measurement. Wind is such a factor in most sites that shielding is essential.

The weighing type of intensity gage is generally accepted as the best intensity gage to use. Rain intensities are needed for many kinds of studies, especially those dealing with surface runoff phenomena. Types of gages are completely covered in:

"Precipitation Measurements Study" by John C. Kurtyka, State of Illinois Water Survey Division. 1953.

The problem of placement of watershed rain gages, either tilted or vertical, has not been solved. The work at San Dimas does not give any real clues. Good judgment and care are needed to select locations for rain gages.

Compilation of rainfall data is best done, in the opinion of the group, by using the Theissen mean of prorating the area of the watershed. This system is faster than the isohyetal method and about as accurate.

Some comments or recommendations were made:

All rain gages should be checked for correct diameter and level of the orifice. If funnel needs to be removed for snow measurement, the ring should be separated from the funnel section and the ring placed back on the gage for ease in maintaining an accurate cutting edge. Oil should be used to prevent evaporation.

STREAMFLOW MEASUREMENT

B. C. Goodell

Techniques of streamflow measurement are based on laws and concepts of fluid mechanics. Such relationships particularly pertinent to stream gaging are as follows:

States of open channel flow

Uniform flow.-- Stream surface is parallel to channel bottom; neither velocity nor cross-sectional area changes with distance along channel.

Nonuniform flow.-- Stream surface is not parallel to channel bottom, velocity and area change with distance along channel.

Steady flow.-- Can be uniform or nonuniform but, at a given point, velocity and cross-sectional area do not change with time.

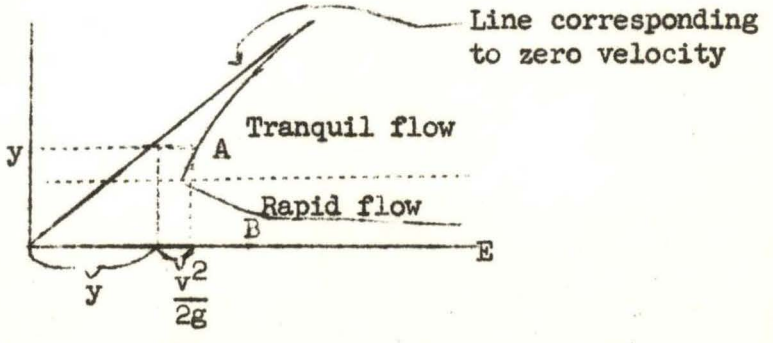
Unsteady flow.-- Characteristics of flow at a given point do change with time. Example: Changing rate of discharge of a stream such as associated with rain or snowmelt.

Tranquil flow and rapid flow.-- Two states of flow differing by the relative values of potential and kinetic energy contained. Explanation involves concept of "specific energy" which equals sum of potential and kinetic energy with reference to floor of channel.

$$E = y + \frac{v^2}{2g}$$

where E is specific energy, y is depth of flow or potential energy, $\frac{v^2}{2g}$ is "velocity head" or kinetic energy. Latter term stems from equation for velocity of a body falling in a vacuum: $V = \sqrt{2gh}$ where V is velocity after fall through distance h and g is the gravitational constant.

If E is plotted against y with rate of discharge constant:



The point on the curve where E is a minimum is the point of "critical depth" and "critical velocity." At greater values of y the flow is tranquil. At lesser values of y the flow is rapid. To illustrate the relative values of y and $\frac{V^2}{2g}$ under tranquil flow, consider point A. Here the potential head y comprises most of the specific energy. At point B, where we have the rapid state of flow, E is largely made up of velocity head or kinetic energy.

The field test of whether the flow is tranquil or rapid is to place one's finger or a stick vertically in the stream at the point of interest. If a wave pattern appears upstream from the obstacle, the flow is tranquil. If only a sharp jump in the surface occurs at the obstacle with no disturbance of the surface upstream, the flow is rapid. The explanation of this behavior difference is that under rapid flow, the velocity of flow is greater than the possible velocity of a surface wave. Thus a wave cannot move upstream. Under tranquil flow, the velocity of a wave is greater than the velocity of the stream and a wave can move upstream.

Tranquil flow may also be distinguished from rapid by the behavior of the stream surface over an obstacle such as boulder. The obstacle causes a loss of specific energy. As shown in the above figure, if the stream is in tranquil flow a loss of energy will cause a reduction in depth and a depression of the surface will appear over the boulder. In the case of rapid flow, the loss of energy will cause an increase in depth and a standing wave will exist over the obstacle.

The characteristics of tranquil and rapid flow are particularly pertinent to the design and use of flumes for gaging streamflow. Flumes and other structures for stream gaging will be discussed presently; first, I wish to cover several nonstructural means of measuring streamflow.

Measuring devices--nonstructural

Fundamental equation is $Q = AV$ where Q is discharge, A is cross-sectional area of flow, V is velocity. "A" is easily obtained. "V" may be measured by current meter, velocity head rod, pitot tube, deflection vane, salt slug, dye, or floating chip. In velocity measurement, the distribution of velocity with depth below the surface is important. Usually the velocity increases with depth to a maximum at a short distance below the surface, then decreases to the channel bottom. The surface velocity is nearly always less than maximum although no complete explanation exists for this retardation.

Current meter

Commonly used at 0.6 depth below surface. Sometimes measurements at 0.2 and 0.8 depth are averaged for the mean velocity. The latter method is considered more accurate.

(Hoover pointed out that present practice by USGS is to get an integrated value for velocity by vertical traverses of the stream.)

Advantage of the current meter is that single or occasional measurements of flow can be taken cheaply and quite accurately. Disadvantages are that the method becomes expensive if frequent observations are required, accuracy suffers when channel is rough as in most mountain streams, shallow flows cannot be measured because of physical dimensions of meter, meter is easily damaged and fairly expensive.

Velocity head rod

Present model (shown) consists of length of aluminum tee with free edge of web machined to a knife edge and graduated in feet, tenths and hundredths. To flange (1 inch wide) is cemented length of steel tape similarly graduated. Depth of flow is read on knife edge, then rod is turned to present flange face to flow and depth plus velocity head is read. Difference between readings is velocity head (h) from which velocity may be determined by equation $V = \sqrt{2gh}$ or $V = 8.02\sqrt{h}$. From several readings across channel the average velocity and the area of flow are found. The product yields the rate of discharge.

The velocity head rod has the limitations of the current meter with respect to frequency of observations. It has not been as thoroughly tested as the current meter but has the advantages of ruggedness and cheapness. It is effective in flow too shallow for current meter use as well as in deeper flows.

Discussion:

Osborne asked about the accuracy of the rod method.

Goodell referred to tests at The Johns Hopkins University where errors of only 2 percent were found.

Rich asked if a "dancing head" on the rod was common, and if so, how it should be read.

Goodell replied that fluctuation in total head is normal and is due to fact that streamlines are not parallel at all times but are unsteady in this respect. When streamlines happen to converge on rod face, highest total head is observed. When they diverge, total head is low. The rule is to read height which persists for more time than does any other height.

Dortignac pointed out that same reference points on stream bottom must be used for total head readings as for depth readings.

Hoover called attention to tables in King's Handbook of Hydraulics relating velocity to velocity head ($V = \sqrt{2gh}$).

Decker asked if the rod gives an accurate indication of average velocity.

Goodell replied that apparently the rod does this.

Rich: Rod may do this because surface velocity is close to average velocity.

Measuring devices - structural

Long flume

If stream to be measured is small, a flume of sufficient length that uniform flow is attained may be practical. Cross-section of flume is immaterial as long as constant throughout. Manning's equation for velocity $V = \frac{1.5}{n} R^{2/3} S^{1/2}$ may be used after few calibration measurements to establish "n" the coefficient of roughness, R is ratio of cross-sectional area to wetted perimeter, S is channel slope.

Parshall flume

This is so-called critical depth flume because flow changes from tranquil to rapid and back to tranquil again. Two stilling wells are used and heads both upstream and downstream of critical depth point are measured. Commonly used in irrigation ditches where much drop in flow through gaging device cannot be tolerated and where natural flow is tranquil. For use on mountain streams it has the disadvantage of being readily subject to sedimentation.

San Dimas flume

This is also a critical depth flume. In use on rapid mountain streams, flow is made to change from rapid to tranquil and back to rapid. It is less susceptible to sedimentation than the Parshall because critical depth is near upper end of flume, while in Parshall the critical depth occurs at near the midlength point and below one point of measurement. In the San Dimas the piezometer opening is downstream from the point of critical depth where the flume slopes sufficiently that the sedimentation hazard is low. A feature of a transition from tranquil to rapid flow is that flow conditions--velocity, depth, etc.--below the point of critical depth are theoretically independent of conditions above that point and vice versa. Thus sedimentation in the zone of tranquil flow above the San Dimas flume should have no effect on the stage-discharge relation. Actually, in the case of our 1-foot San Dimas flume on Fool Creek, sedimentation in the approach

channel does affect the stage-discharge relation, at least during low flows. A limitation common to both the San Dimas and Parshall is that if designed to have capacity for large flows, they are not sensitive to small flows. In this situation a V-notch weir is sometimes used in tandem with a San Dimas flume.

Trapezoidal flume

This type is similar to the San Dimas in principle and performance. Advantages are: Better conformance to natural channel, thus less excavation and less forming; greater range in capacity without as great sacrifice in sensitivity. Disadvantages are: Not as well studied as San Dimas -- no laboratory rating.

Flumes in general

Steel lining of all flumes necessary to prevent erosion of concrete and resultant effect on rating curve. Flumes difficult to winterize because of exposure of piezometer pipes. Two essentials in design of flume: (1) Stage-discharge relation be smooth throughout expected range of flow, (2) stage-discharge relation should be unaffected by changes in the approach channel.

Weirs

Weirs considered most accurate of gaging sections. Have been thoroughly studied. Common types are rectangular with full bottom and end contractions and V-notch which inherently have full contractions. Full contractions are considered to exist if crest of weir is above weir pool floor by at least 2.5 times the highest expected head on the weir and sides of approach channel are distant from sides of weir opening by at least 2.5 times the expected head. If these specifications are followed, the velocity of approach can usually be ignored provided pool has adequate length. King's formula for the discharge of rectangular weirs per foot of length is

$Q = 3.34\ LH^{1.47}\left(1 + 0.56\ \frac{H^2}{d^2}\right)$. The term in parenthesis is the correction for approach velocity. "H" is the head over weir crest. "d" is ratio of cross-sectional area of approach channel to length of weir crest "L". Substitution shows that the term $\frac{H^2}{d^2}$ is actually the ratio of the square of the cross-sectional area of flow through the weir to the square of the cross-sectional area of the approach channel. Given a 4-foot weir crest depth over weir of 1 foot, and channel specifications given above, $\frac{H^2}{d^2}$ is approximately equal to $\frac{1}{64}$. Thus correction term affects Q by by only 1 percent.

Other requisites in weir construction are that crest be level and plumb, be knife-edged and set in wall so nappe springs clear of wall, piezometer openings be 2.5 H upstream.

Advantages of weir are: thoroughly tested, lends itself to accurate installation, easily maintained, easily winterized. Disadvantages are: limited capacity, subject to sedimentation.

Chart reading

Where water yields per month, season, or year are of primary interest, the all-break method of chart reading is wasteful of time and money. The balancing of areas about a transparent straight edge gives adequate accuracy with an expenditure of about one-tenth the time.

Valuable references:

1. Fluid Mechanics-- by R. C. Bender. Prentice-Hall, 1949.

2. Hydraulics of Open Channels-- by Boris A. Bahkmeteff. McGraw-Hill Book Co., 1932.

3. Handbook of Hydraulics-- by H. W. King. McGraw-Hill Book Co., 1939.

SEDIMENT MEASUREMENTS

L. R. Rich

All land management practices change sediment movement and sediment content of streams. Also, any method that measures sediment yields or sediment movement also changes sediment flow patterns. Our aim should be to determine what we want and if possible standardize on methods of measurement. Generally we are interested in comparisons of sediment measurements before and after some land management treatments or practices.

I. Sediment is moved in the following ways:

A. Raindrop splash (detachment) (Ellison, AGU 1945)
B. Sheet flow
C. In gullies
(1) Varies as depth and velocity, but streams seldom if ever carry a full load of sediment.

(2) Bed load and suspended load. Streams vary in proportion of bed load and suspended load. Shape of channel is a good indication of type of sediment carried and needs for sampling.

There is no good way to measure bed load. Suspended load samplers have been standardized (D-43, D-49, D-50, etc.).

II. Measurement of sediment from runoff plots

A. Tank measurements and weighing sediment from small plots such as Base Rock plots.
B. Tank measurements from small watersheds where all water and sediment is held. Combination of volume measurements and samples of bulk density.
C. From weir ponds where most of the water flows through, such as over a weir. Coarse sediment is trapped in pond, but suspended sediment moves through the weir pond and must be sampled separately.

These structures cause unnatural flow conditions. Cutoff walls act as check dams and prevent formation of gullies or form new base levels of cutting.

III. Sediment Measurements from stock tanks and ponds

Profile and cross section measurements or contour mapping before and after. Need bulk density measurements. Without bulk density measurements, compaction through the years may indicate decreasing sediment yields. A possible example is given by the successive sediment surveys of Elephant Butte reservoir. Sediment accumulation has shown the following trend with time: 28,000, 23,000, 18,000, 13,000 10,000, and 4,000 acre-feet per year.

These measurements must also be tied to amount and type of flows as well as type of land management.

IV. Streams

A recent survey of suspended sediment measurements indicated a wide variety of sediment samplers and sampling. A standardization program developed the D-43, D-49 and D-50 samplers that take samples (both integrated and point samplers) with very small disturbances to natural flow. These samplers are for large streams.

Most of the large streams of the Southwest carry or contribute surprisingly similar loads of sediment when expressed in terms of sediment contribution per unit of area per year. Our problem is to get samples from our smaller streams in our research areas and smaller experimental watersheds. We need similar standardization for smaller streams.

Discussion brought out the following points:

1. A possible sampler, liquid nitrogen in a $\frac{1}{2}$ inch pipe to freeze the sediment in place. This would do what every other sampler does to varying degrees, that is, change the flow pattern of the stream.

2. Lightbeam turbidity meter in place. (This type of sampler is being studied).

3. Many samplers have the problem of recirculation. It has been eliminated in many.

4. The single shot sampler does not recirculate. (This may be a sampler that has possibilities of general application in dew work).

5. Glass cages and photos were suggested. (These have been tried).

6. Objective of sampling should be clear. Bureau of Reclamation wants sand, silt, and clay fractions for channel stability and reservoir compaction. Forest Service interested in both weights and volumes for before and after comparisons. Also for actual sediment yields.

7. Hans Einstein method has value for bed load determination in alluvial channels.

8. There is a problem of inadequate samples.

9. The problem of relating sediment samples back to the watershed is often masked by channel deposits.

10. Total sediment and suspended sediment are not correlated in all streams. It may be in some streams such as the Colorado where suspended sediment may be a major part of the total sediment.

11. Weekly samples, such as at Workman Creek, are of questionable value.

12. Measurements taken too infrequently have not produced good data.

13. Pretreatment data are of questionable value even though little or no sediment was measured.

14. Weir basins are no good for complete sediment measurements. Their value is limited to heavy sediments.

15. Little chance for standardization because of different conditions and different objectives.

16. Frequent samples will be taken at Black Mesa.

17. Sediment transportation is not a problem of the Forest Service.

18. Volume measurements are of little value because of variations in shrinkage.

19. The question of how much sediment is too much, should have no place in our thinking.

20. Our job is to find effect of treatments on sediment yields (measurements must be good).

21. We must know the relationship between sediment load and storm size.

SOIL STRUCTURE

Howard Orr

Soil structure is defined as the arrangement of soil particles. The particles aggregate into units classified as platy, prismatic, columnar, angular blocky, subangular blocky, granular, or crumb. If there is no aggregation as in coarse sands the soil is described as structureless. Each structural class is further described as to strength or distinctness of units, and size.

The classification of structure is useful in characterizing soils but does not provide a quantitative measure that can be used in evaluating land use or treatment.

Following these preliminary remarks there was a discussion of factors that influence the natural development of structure. These include soil texture, organic matter, alternate wetting and drying, freezing and thawing, fire, and biotic agents.

Soil structure can be measured by direct or indirect methods. Direct methods involve microscopic examination or photographing of soil fragments or sections to study the large pore space and arrangement of soil particles. Because these direct methods are more qualitative than quantitative they are not widely used to measure the effects of land use or treatment.

Indirect methods involve measurements of factors that are dependent on structure. The first is measurement of the extent and stability of soil aggregates. This can be done by dry or wet sieving, elutriation, or sedimentation. These measurements are not used extensively in watershed work but it was pointed out that they can be useful to determine resistance of soils to erosion.

Other factors that depend on structure are air and water capacity of soils, and air and water movement in soils. All these factors are related to the volume of soil pores. Their measurement therefore involves some measurement of soil pore space.

Total pore space can be determined directly from the bulk density and true specific gravity of the soil solids. The point was stressed that total pore space includes capillary pores that retain water against the pull of gravity and the macropores that cannot hold water. Air capacity, percolation, and infiltration are all dependent on macropore space. Conditions are most favorable for plant growth where macropore space is about 50 percent of total pore space.

Macropore space is particularly subject to alteration by

disturbance of the soil. Measurement of both micro and pore space is therefore a valuable means of evaluating effects of land use and treatment.

Methods for measuring pore space were discussed. Perhaps the most widely used is the tension table with which it is possible to measure the distribution of volume of large pores drained at up to 60 centimeters water tension. Water held at 60-centimeter tension is generally considered as the maximum volume of water retained for plant growth. Pore space can also be measured at a wide range of tensions with the pressure membrane apparatus which is also commonly used to obtain the wilting coefficient of soil. Porous plate apparatus is also used to measure pore space mainly at low tensions to obtain an approximation of field capacity of soil.

Air capacity is considered synonymous with large pore space and can therefore be measured in the same way.

Rate of air movement in soils is measured with some type of soil-air permeameter. A large number of rather simple devices have been developed.

Rate of water movement in soils can be measured with some type of infiltrometer in the field or by measurement of the rates of water percolation through soil cores in the laboratory.

Soil texture influences the type and strength of structural development. Noncohesive sands are structureless. Sandy soils generally have weak structure and do not show a wide variety of structural types. The finer the soil texture the wider the range of structural types that is possible because of the strong binding qualities of colloidal clay and organic matter. It was brought out that most soils compact more easily when wet. It therefore may be desirable to restrict logging, grazing, or other land use when soils are wet.

Vegetation promotes aggregation of soils by contributing organic matter, and root channels promote rapid percolation of water. Vegetative canopy protects the soil surface from impact of raindrops, preventing dispersal of soil aggregates and sealing of soil pores. Other factors that promote recovery from soil compaction are alternate wetting and drying, freezing and thawing, in some cases fire, and activity of soil fauna and bacteria.

It was stressed that many of the factors involved in soil structure can be determined by methods of simple soil mechanics.

SOIL MOISTURE MOVEMENT

H. E. Brown

Introduction

1. Personal observations during flash flood at Badger Wash in 1954: low infiltration rates resulting in rapid runoff.

2. The other extreme in infiltration and percolation at Seabrook Farms.

3. There are 2 phases in soil moisture movement.
   a. Infiltration and percolation
   b. Retention or storage

   Both affect the amount of water which runs off or enters the soil.

Soil moisture constants

1. "Constants" (field capacity, wilting point, saturation capacity) are involved in the retention-storage phase.

2. A good approach is to think of the soil layer as a great moisture reservoir, with moisture coming and going all the time. (To get an idea of this process remember that herbaceous plants may use 500-700 pounds of water to produce 1 pound of dry herbage).

   The capacity of this reservoir is limited at the upper limit by field capacity and at the lower limit by wilting.

   Field capacity - gravitational and lateral movement extremely slow - 1/3 atmosphere.

   Wilting point - moisture ceases to be available to plant roots - 15 atmospheres.

   Saturation capacity - soil saturated with water, though all of pore space never filled because of entrapped air.

   Field capacity varies from 8 percent (coarse soils) to 40 percent (fine).
   Wilting point varies from 3 percent (coarse soils) to 23 percent (fine).

Movement of soil moisture

Chiefly the processes of infiltration (process by which water enters the surface soil) and percolation (movement of water below the surface).

Infiltration: Influenced by:

a. texture of soil - decreases with fineness
b. moisture content - decreases proportionally
c. turbidity of water - decreases with turbidity
d. soil and water temperature - decreases with colder temperature
e. freezing - decreases
f. size and velocity of drops - decreases with size and velocity
g. humus type (2.7 times as great with mull
h. as with mor (Day, 1940)
i. rock type - greater with igneous than with sedimentary

most important
j. noncapillary porosity
k. surface litter
l. grazing intensity at Manitou

Light	(15-20 percent utilization)	= 1.87 inches per hour
Moderate	(35-40 percent utilization)	= 1.94 inches per hour
Heavy	(+ 50 percent utilization)	= 1.52 inches per hour

(least significant difference = ± 0.35)

(litter present = 1.52 inches per hour vs. bare ((litter removed) = 0.92 under ponderosa pine - (Johnson)

Percolation:

Less in literature

Tarrant. -- Heavy burning reduced percolation rate (60 to 15 cubic inches per hour) Prescribed burning increased percolation rate (5 to 9 cubic inches per hour)

Suman and Hall. -- Percolation rates reduced by grazing and burning on southeast coastal range.

Percolation in rock strata: granites and similar rocks carry little water; lava, sandstones and limestones may carry a great deal. Fall River in California has 24 inches annual precipitation and 30 inches of streamflow -- underlain by porous lava formations where water enters from outside.

Temporary storage in rock strata in southern California estimated at 20 to 40 inches by Rowe.

Measurement of infiltration

Three main methods: ring, rainfall simulator, analysis of rainfall-runoff records.

Ring infiltrometer

Metal cylinder with diameter larger than 9 inches
Drive 6 inches in ground, add water, measure rate of intake
Protect from puddling
Buffer may be needed
Fluctuating or constant (3-5 inches) head

Rainfall simulator

Artificial rainfall applied to plot; measure rain, runoff, erosion; compute infiltration

Types:
a. Pearse - piddler - 1 foot square
b. North Fork) to 8 square feet
c. FA)
d. F - 6.6 x 12 feet
e. Rocky Mountain

Infiltration rates may be satisfactory but are only relative.

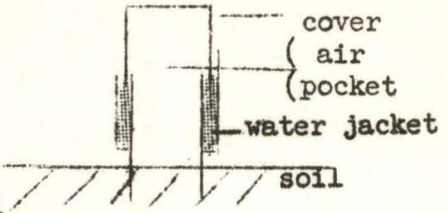
ANALYSIS OF RAINFALL-RUNOFF RECORDS

Measurement of soil permeability

Will describe two methods: permeability to air: air permeameter
permeability to water: percolations

Air permeameters described by Grover, Iowa Agr. Expt. Sta.

Good for thin surface layers. Does not cause soil disturbance. Cover drops slowly by gravity into water jacket, forcing air into soil. Measure rate of drop as index of permeability of soil in air.



Percolation measurement

Samples collected by 2 methods: Pit (Ref. Hoover, Olson, Metz) Machine (Utah soil sampler)

Prepare sample
- cheesecloth on bottom of core
- determine fresh weight
- attach head ring
- place in permeameter cup

Laboratory test
- saturate core from bottom up
- apply constant head of water to top of core
- run water through 5-10 minutes till constant rate
- measure percolate at 5, 10, 20 minutes
- determine percolation rate in inches per hour

Discussion on soil moisture movement

1. Constants such as field capacity and wilting point are better thought of as characteristics of the soil rather than constants. Since these characteristics are not precise but have variations, better we think of them as such.

2. Desirability of taking 4-inch vs. 2-inch cores for porosity.

3. Calcium in litter increases infiltration in South.

4. Stratification by soil survey and cover type should be basis for infiltration sampling.

Infiltration

5. Impossible to characterize pastures or watershed with infiltrometer. But can characterize certain homogeneous conditions (areas); these results then may be applied to comparable situations elsewhere.

6. If infiltration rate is the factor which creates critical runoff conditions then infiltrometer can be used to measure. If storage capacity is limiting, use other means of measurement.

7. Resistance to wetting not measurable on infiltromer plots because of excessive sealing from drop impact. Possibility of removal of fine soil particles from surface by raindrop splash with consequent improvement of infiltration.

8. Fact that surface runoff heads cannot develop on an infiltrometer plot as on a large area because of its small size - consequently runoff characteristics not comparable to watersheds, only relative.

9. Advantage of wet run in standardizing infiltrometer measurements. Dry runs closely correlated to wet runs at Manitou.

10. Use of fog nozzle reduces sealing of artificially applied high intensity rainfall (North Fork infiltrometer) - precautions needed against wind drifting.

Percolation

11. Laboratory percolation tests can define limiting layers in soil profile -- impossible with infiltrometer in field.

12. Need to keep air from becoming trapped in core which may result if water not warmer than soil sample. Can de-aerate water. Should follow USGS method.

MEASUREMENT OF SOIL MOISTURE

E. J. Dortignac

Soil moisture has been a topic of great interest for more than 100 years. The difficulties involved have led to the development of many new ways of measuring moisture. Probably more than 400 references discuss or contain information related to methods of measurement. Two Forest Service experiment station papers[1/] cover most of the important methods used in measuring soil moisture.

Methods for measuring soil moisture may be considered under 2 broad categories; those concerned with measurement of soil moisture in situ and those made on a sample extracted from the soil profile. This is an important classification because continuous soil moisture samples cannot be obtained at the same point in situ when soil samples are removed from the soil profile. This broad classification may be further divided into the direct and indirect methods of measuring soil water. In the direct method the water content in the soil is obtained by weight, by volume, or by counting the hydrogen atoms in the free water molecules. In contrast, the indirect method utilizes measurement of properties associated with soil moisture either directly in the soil or in porous media in equilibrium with the soil. These involve measurement of electrical resistance (or conductance), capacitance, dielectric, thermal, and tension properties of soils.

Soil moisture methods will, therefore, be discussed according to these broad classifications as outlined below:

1. Extraction of soil samples

    1.1 Methods used in obtaining samples
    1.2 Difficulties in obtaining samples

1/ Lull, Howard W. and Kenneth G. Reinhart
1955. Soil-moisture measurement. Occasional Paper 140, Southern Forest Experiment Station.

Olson, David F. and Marvin D. Hoover
1954. Methods of soil moisture determination under field conditions. Station Paper No. 38. Southeastern Forest Experiment Station.

1.3 Methods of measuring soil moisture
1.31 Direct methods
1.311 Gravimetric
1.3111 Oven-drying
1.3112 Other methods used in drying soil
1.312 Volumetric
1.32 Indirect methods
1.321 Heat of solution
1.322 Alcohol method (Bouyoucos)
1.323 Air pycnometer
1.324 Hygrophotographic

2. Soil in situ (in place)

2.1 Direct methods
2.11 Lysimeters (weighing)
2.12 Soil pots (weighing)
2.13 Nuclear

2.2 Indirect methods
2.21 Porous media in soil
2.22 Electrical methods
2.221 Resistance (conductance)
2.222 Capacitance
2.223 Dielectric
2.23 Thermal conductivity of soil mass
2.24 Tensiometers
2.25 Penetrometers

3. Calibration of methods used in measuring soil water in situ

3.1 Need for calibration
3.2 Difficulty involved in calibration

4. Evaluation of methods

4.1 Accuracy and reliability
4.2 Temperature
4.3 Salt
4.4 Ease and speed of measurement
4.5 Durability
4.6 Cost of instruments

5. Recording instruments

6. Soil moisture variation in sampling

6.1 Depths
6.2 Horizontal stratum
6.3 Uneven distribution of infiltrated water
6.4 Vegetation

6.41 Aerial plant parts
6.42 Roots

7. Estimates based on meteorological factors

EXTRACTION OF SOIL SAMPLES

Methods used in obtaining samples

Soil samples may be obtained with a shovel, spade, trowel, tube, and auger. In rocky soils or when soils are wet and sticky the shovel, trowel and spade can be used to good advantage. These tools are also handy for extracting soil samples in the upper soil horizons.

The King tube (7/8 inch diameter) is most frequently used in soil sampling. The tube is driven into the ground with a 15 lb. hammer and extracted with a jack when driven more than 3 or 4 feet into dry soil.

Two types of augers are used in obtaining soil samples. The screw auger is frequently used in conjunction with soil type mapping and surveys. The modified posthole (Retzer) auger can be constructed with an inside diameter ranging between 2 and 5 inches, depending on the purpose and conditions of sampling.

Under favorable conditions, and with 2 or more sizes, the Retzer auger has been used to depths of 30 feet (Guayule Project).

Difficulties in obtaining samples

The type of sampling instrument to be used is dependent on the soil conditions that are likely to be encountered. None of the above instruments are suitable for obtaining volume measurements (bulk density) of soil cores. The minimum inside diameter for this latter purpose is about 3 inches.

In extremely rocky soils the shovel works best, but the Retzer auger has been used successfully. The Retzer auger is better than the soil tube under very wet conditions or in very dry soils. The soil in the cylinder must be compacted by tamping prior to extraction of the auger.

With the free water in the soil, moisture content can never be measured accurately when the soil sample is removed from the soil profile. Where a wet layer overlies a dry horizon, dry samples most often are contaminated. Wet instruments cause additional contamination. When the soil is dry and hard, insertion and extraction of

augers and tubes are difficult. Oftentimes the soil sample will slide out of the instrument as it is withdrawn from the soil.

Methods of soil moisture measurement - Gravimetric

The gravimetric method is the standard procedure used in measuring soil moisture. It is also used as the basis for checking or calibrating other methods.

The method involves weighing the extracted soil sample stored in an air-tight container, oven drying for 24 hours at 105°C or until the change in weight of the soil becomes constant, and re-weighing the dry soil sample. Moisture content is commonly expressed as a percent by weight:

$$\text{Percent by weight} = \frac{\text{Weight of water (100)}}{\text{Weight of oven-dry soil}}$$

The water content of the soil in percent by volume is of greater value and usefulness in hydrologic studies and appraisals. Moisture content may be expressed in percent by volume or in inches depth of water. This evaluation requires the measurement of soil volume as well as weight of soil and the resultant ratio is referred to as volume weight or bulk density. Thus,

$$\text{Percent by volume} = \text{Percent by weight (bulk density of soil)}$$

or

$$\text{Moisture content (inches depth)} = \frac{\text{Moisture Percent (by volume)} \left[\text{Soil depth (in inches)}\right]}{100}$$

Drying soils

Oftentimes there is a need for obtaining the moisture content of an extracted soil sample in a relatively short period of time. Because of this need many methods have been proposed for drying soil samples. Perhaps the best method is to dry the soil in a forced-draft oven at 130°C. This method, which requires only 2 to 3 hours of drying, is not recommended when the organic content of the soil exceeds 3 to 5 percent by weight.

Desiccants such as Desichlora (barium perchlorate), Drierite (anhydrous calcium sulphate), and water-absorbing liquids have been used to avoid the 24-hour oven-drying time but usually require almost as long and seldom are as accurate.

The calcium carbide method based upon the reaction of calcium carbide with free water is a most useful field method. It has been successfully used on the Guayule Project. It works well on coarse and medium textured soils and has promise for use in nurseries and other irrigated projects.

The Bouyoucos method which involves addition of alcohol and burning off the alcohol to remove the water requires about 5 minutes to make a determination. Moisture percentages obtained in this manner are slightly higher than by oven-drying.

Volumetric methods

Several methods based on the measurement of the volume of water in the extracted soil sample have been devised. The constant-volume method is perhaps the best known and most practical. Water is added to a soil sample to make up a constant volume. Fifty-gram samples of soil are frequently used and water is added to make 100 cc. The difference between the weight of the soil-water volume and the weight of an equal volume of water, when multiplied by a pre-determined factor, gives the oven-dry weight of the soil.

Soil moisture content has been determined by adding xylol or toluene to a sample, distilling off the liquids and measuring volumetrically the distilled water. The process requires about 45 minutes.

Heat of solution

Method utilizes the process that a mixture of water and concentrated sulphuric acid produces heat in proportion to the quantities mixed. The most common procedure is to mix 2 cc. of acid with 1 gram of soil and measure the rise in temperature of the solution. This method is accurate to about ½% moisture content, when extreme care is exercised in measuring the volume of acid and weight of soil. Since only one gram of soil is used in the method, it is not considered satisfactory for our use.

Bouyoucos alcohol method

Bouyoucos described the alcohol method which consists of mechanically dispersing a 25-gm. soil sample in 75 cc. of pure methyl alcohol, filtering the solution and determing its specific gravity with a special alcohol hydrometer. The method is accurate but requires about 3 times as much time as needed in oven-drying.

Air-pycnometer (Russell)

A soil core is placed in an air-tight system at barometric pressure. The volume of the system is changed a given amount and the resultant pressure is measured. The moisture content of the soil can then be computed if the real specific gravity is known since the volume of the system, the volume of the change, the volume of the sample and the associated barometric pressures are known. This method is not satisfactory for soils containing more than 5 percent organic matter nor for stony soils. The air-pycnometer is suitable for determining bulk densities of soils but is not recommended for determination of soil moisture.

Hygrophotographic method

A plate or film of silver bromide can be treated in such a manner that permits images and patterns to be recorded under the combined action of, first, light and then humidity. This gives a photographic method for determination of moisture in the field. The preparation of the plate or film involves about 8 processes until a stable and insoluble double salt of mercury and silver is obtained. It is sensitive to light and, on being exposed, the color changes rapidly from yellow to violet black. After exposure, it is extremely sensitive to water and atmospheric moisture which restores it to its original yellow color. This method may also have possibilities for measurement of the water content of snow.

SOIL IN SITU

Lysimeters

The weighing lysimeter such as used at Coshocton, Ohio, is an accurate method of directly measuring soil moisture changes. The method is very accurate for bare soils but when plants are present, corrections for changes in plant weights and for interception of precipitation are needed.

Soil pots

These are useful in measuring soil moisture changes at a given point. Pots are usually removed from the ground at each weighing, thereby requiring but a single platform scale. This type of equipment proved satisfactory for measuring soil moisture as affected by wind reduction from artificial and natural barriers on the Shelterbelt Project. The main objection to the method is that concerned with soil disturbance involved in preparing pots. The continuity of the soil mass is also broken when pots are inserted in the soil.

Nuclear method

This method is based on the physical laws governing the scattering of neutrons in the soil. It depends on a source of fast neutrons, the slowing down of these neutrons by water in the soil and finally measuring the slow neutrons in the soil mass.

When a fast neutron source is placed in the soil, the emitted neutrons collide with the atoms comprising the soil. Neutrons are thus scattered in all directions and some return to the vicinity of the source. The neutron loses part of its kinetic energy and is slowed down by each collision. The average energy loss is much greater in neutron collisions with atoms of low atomic weight such as hydrogen.

As a result, the number of slow neutrons found near the source is a function of the number of atoms of low atomic weight present in the soil. Since hydrogen is the only element of low atomic weight found in soils in appreciable quantities and as hydrogen is largely contained in molecules of free water, the slow neutron count is a direct measure of the moisture content of the soil.

The method gives the amount of water per unit volume of soil. If moisture content by weight is needed, bulk density may be obtained with nuclear equipment which utilizes gamma rays.

As the relationship between neutron count and moisture content is mostly independent of soil characteristics, theoretically, only one calibration curve should be needed for all locations. Measurement of soil water is independent of its physical and chemical state in the soil, hence variables such as temperature, salt concentration and texture are eliminated. However, variation in organic content is a source of error.

Porous media in soils

The most frequently used method of determining soil moisture changes at a given point utilizes the determination of moisture in porous media in moisture equilibrium with the soil.

The first method involved the use of small, porous-porcelain cones all having approximately the same surface area in contact with the soil. The amount of water absorbed by the cone from the soil is an approximate measurement of the water in the surrounding soil. Cones were usually left in contact with the soil for 2 to 3 hours. Soil moisture is determined by weighing the cone plus water and comparing this weight with that of the oven-dried cone.

A refinement consists of a porous chamber installed in the soil and containing a closely fitted tapered porous plug which can be removed through a tube with a hook for weighing. An additional refinement involves adding washed sand to the inner portion of the plug. This provides a range of large pore sizes.

Electrical methods

The electrical methods are indirect methods of measuring soil moisture and utilize relationships that exist between water and electrical properties.

Resistance (conductance)

This method is based on the principle that electrical resistance of the soil decreases as the water content increases. It measures soil moisture indirectly through measurement of soil tension and is thus subject to hysteresis, when converted to soil water quantities. Present use involves measurement of electrical resistance between 2 electrodes embedded permanently in the soil at the required depth and fixed in: gypsum block, nylon fabric, fiberglas, or a combination of these.

The first attempt to use this principle was made before the turn of the century. Soil electrodes consisting of carbon plates were placed directly in the soil and the electrical resistance was measured with a Wheatstone Bridge. One important objection to this 2-electrode method of measuring electrical resistance in the soil is that the method measures the sum of the soil resistance and contact resistance between the electrode and the soil. Another objection is due to the fact that small changes in the salt content of the soil solution affect the resistance more than the amount of water present.

To overcome the above difficulties, Bouyoucos and Mick embedded electrodes in gypsum or plaster-of-Paris blocks. These blocks supply a good soil contact and provide a buffering effect which overcomes the effect of salt content in the soil. Periodic changes in soil density and compaction are also overcome by use of the porous block. Soil moisture resistances of individual plaster-of-Paris blocks are measured with a modified Wheatstone Bridge.

Bouyoucos later utilized a nylon fabric as a porous medium and has, more recently, attempted to combine the plaster-of-Paris block with the nylon fabric. This latter unit provides a rather wide distribution of pore sizes and should, therefore, represent more accurately the changes in soil moisture between field saturation and wilting point.

Colman and Hendrix contributed the fiberglas unit. Electrical resistance is measured between 2 Monel metal screens separated by 2 layers of fiberglas cloth. This assembly is enclosed by 3 layers of fiberglas cloth and bound in a Monel metal case, spot welded at the edges. The fiberglas unit contains a thermistor, thus permitting measurement of soil moisture temperatures. The resistance between electrodes is read with a battery-operated alternating-current ohmmeter.

The thermistor unit provides a means for correcting resistance readings to constant temperature as well as supplying a measurement of soil temperature changes. For example, uncorrected soil moisture content may be in error by rather large amounts:

Temperature	Uncorrected moisture content	Corrected moisture content
	Inches of water per 3 inches of soil	
30°F	0.80	0.68
90°F	0.80	0.90

A combined gypsum-fiberglas unit was developed by Youker and Dreibelbis. The plaster-of-Paris block serves as a good buffer and soil contact and the fiberglas provides useful data in the wet range. Oftentimes, in coarse gravelly or rocky soils, it is not possible to obtain a good permanent contact with any of the designed porous media. In such instances, fine-textured soil should be placed around the porous media.

Capacitance

This method involves the determination of the electrical capacity of the 2-electrode plaster-of-Paris block as an indicator of soil moisture content.

The capacity for electricity decreases from about 0.070 microfarads at field capacity to about 0.0003 microfarads at near wilting point.

Dielectric method

This procedure is based on the well-known fact that water has a relatively high dielectric constant and the soil a low one. The resonance method is used in determining the dielectric by hooking up condensers so that the sum of their capacities, plus the one condenser buried in the soil, is constant. The method has never been adequately field tested but should be only slightly affected by salt and temperature changes.

Thermal conductivity

This method is based on the principle that heat conductivity of the soil increases with increased moisture content. The size of the current is an index of the amount of moisture in the soil.

The apparatus consists of a modified Wheatstone Bridge arrangement in which one arm, buried in the soil, consists of a coil of enameled copper wire wound onto glass tubing. A 6-volt battery provides the source of current which is measured with a microammeter.

Tensiometers

Tensiometers measure directly the moisture tension existent in the soil. Instruments are composed of a porous clay pot, glass or metal tubing, and a mercury manometer or Bourdon-type vacuum gage. Soil moisture tensions may be obtained from zero to about 0.90 atmosphere. Field installations have been made to the 15-foot depth. Tensiometer readings are subject to diurnal fluctuations caused by temperature gradients between the porous cup and the surrounding soil.

Penetrometers

Moisture content can be estimated by relating it to the force required to push a probe or penetrometer into and through the soil. This method gives only a rough approximation and has little value in rocky, stony, and dry soils.

CALIBRATION OF INDIRECT METHODS

All methods should be calibrated or checked against the gravimetric method whenever actual quantities of water per unit volume of soil are desired. However, there is no need to calibrate electrical or other units when relative values are needed. For example, in predicting streamflow from snow water and soil moisture measurements obtained in snow surveys there may be no need for calibration of units.

The log of the resistance or dial readings obtained from the ohmmeter are indices of soil moisture. Since streamflow is predicted on the basis of the ratio of current snow-water content to average long-term water content, a similar index may be developed for soil moisture content to aid in forecasting.

When a calibration is essential, it should be accomplished in the field. Laboratory calibrations are unreliable and fail to provide the same relations obtained from soil in situ. The field procedure involves taking gravimetric samples from an area close to the stack of electrical units and relating the measured resistances to actual soil-moisture content. The gravimetric sampling plot should be taken close enough to the units to represent similar soil and moisture conditions, yet sufficiently distant to avoid disturbance of natural soil surrounding the stack of electrical units. The area should be large enough to avoid disturbances caused through repeated sampling.

A calibration curve relating soil moisture content (percent by weight or volume) or moisture tension to the logarithm of the resistance (in ohms) can be developed with about 20 paired measurements well distributed from wet to dry soil conditions.

Difficulties in calibration are caused by the variation between extracted soil samples and that surrounding the electrical units. Soil variations include texture, density (bulk and real), organic content, and soil chemical state. Variation in root systems between the 2 spots further complicate measurements. This is also true in regard to soil moisture conditions which vary with interception, infiltration, percolation, and microclimate between any 2 spots.

EVALUATION OF METHODS

The electrical-resistance, capacitance, dielectric, thermal conductivity, tensiometer and nuclear methods were all designed to give in situ changes in soil moisture. This is extremely important and a distinct advantage over the gravimetric method in which the sampling point is destroyed. The development of methods used in predicting soil moisture accretion and depletion at the Vicksburg Infiltration Project would never have been possible with the gravimetric method and plot-area approach. The point sampling method is the only satisfactory approach in developing and understanding principles involved in soil-water-plant relations.

It has been mentioned that field calibration of in situ instruments tends to reduce their point significance, lending the data an areal significance. But this is actually an advantage rather than a criticism of the method. Moreover, the need for and methods used in calibration of instruments have been grossly overemphasized. With a little ingenuity it is relatively easy to calibrate most instruments. When a knowledge of available or growth water is needed, units can be calibrated against soil moisture tension which gives a much more reliable correlation with electrical resistances.

Accuracy and reliability

Electrical-resistance units are the most responsive to moisture changes between field capacity and wilting point. The fabric units are superior to the gypsum block in regard to distribution of pore sizes and give fairly good measurements in the wet range above field capacity.

A combination of fabric and gypsum should give the most consistent results. The gypsum block has a coefficient of variation of 15 percent of the mean when measuring soil moisture tension.

Tensiometers are the best instruments for measuring soil moisture between field capacity and field saturation. They lose their value where soils are subjected to repeated and frequent drying out.

A source of error in electrical-units and tensiometers is attributed to hysteresis -- the tendency of the unit at a given soil moisture tension to be higher during soil drying than during soil wetting.

Nuclear instruments have not been thoroughly tested but they hold promise. Good correlations have been obtained between the gravimetric and neutron readings. For example, a correlation coefficient of 0,95 was obtained for the 12- to 50-inch depth and 0,76 for the 6-inch horizon. The lower correlation at the 6-inch level was attributed to the escape of slow neutrons from the soil mass without detection.

The neutron method is independent of the physical or chemical state of soil water and hence such variables as temperature, salt concentration, and soil texture are eliminated. Since soil moisture is measured directly, hysteresis effects are avoided unless conversion of soil moisture content to moisture tension is desired.

Temperature

The nuclear and gravimetric methods are not affected by temperature changes. Resistance measurements should be adjusted to a common temperature. The thermistor in the fiberglas unit provides a means for such conversions.

Daily variations due to temperature gradients between the tensiometer porous cup and the surrounding soil can be minimized by taking instrument readings at the same time each morning.

Salt concentration

Salt concentration in the soil does not affect the nuclear, gravimetric, nor tensiometer methods. All electrical-resistance unit readings are affected by varying amounts of salt. The fabric units are affected most and the gypsum block the least. The buffering action of the blocks is adequate to give reliable readings in soils containing up to ½ percent salinity.

Ease and speed of measurement

The time required for each nuclear determination is greater than that required by resistance methods but much less than required by the gravimetric sampling method. The tensiometer requires the least effort in securing frequent soil moisture measurements. If the nuclear method can be developed to a point where only one calibration will be needed for all soils, it will be the simplest and easiest method.

Durability

All of the above-mentioned instruments with the exception of the nuclear equipment are very durable. The nuclear equipment breaks down quite frequently. The tendency of plaster-of-Paris blocks to dissolve in wet soils has been corrected by impregnating blocks with a nylon plastic resin.

Relative cost of instrumentation

Gravimetric -- $50 to $75
Electrical resistance -- $200 to $300
Tensiometers -- $25 per unit
Nuclear -- $1,400

RECORDING INSTRUMENTS

When continuous or daily measurements of soil moisture are needed a recording device should be attached to the moisture units. Recording devices are also invaluable where units are located at some distance from work headquarters. Moreover, they provide a means of measuring soil moisture accretion and rapid moisture movement through the profile soon after rainfall ceases.

Korty and Kohnke connected a recording potentiometer with an ohmmeter circuit to nylon units for continuous measurement of soil moisture changes. Richards and Gardner attached a recording vacuum gage to a tensiometer for a continuous record of soil moisture tension.

VARIATION IN SAMPLING

Any method such as the gravimetric which requires removal of soil samples from the soil profile is subject to considerable errors when measurement of soil moisture changes with time are needed. This method is reliable for determining moisture content on a particular day. A mean or average value for a plot may be obtained to the accuracy desired and is solely dependent on the number of samples collected at any one time. But the reliability of the method ends as soon as moisture changes with time are needed, for adequate sampling of a plot alters its natural condition and reduces its usefulness in subsequent sampling.

Soil physical characteristics and moisture variation from spot to spot affect sampling techniques and accuracy of measurements. Thus, variation in moisture content will vary widely over any given area. On well-vegetated sites, the variation in moisture is usually less as the soil dries because the entire soil mass is well occupied by roots.

Soil variation in development of profile, texture, bulk density, real density, and organic content exists over the most homogeneous areas. Uneven disposition of the precipitation caused by variation in interception, infiltration, percolation, and evaporation accounts for a major part of the variation in soil moisture. Variation in rainfall, elevation, microrelief, and vegetation composition, density and vigor all add to the uneven distribution of water in the soil mass.

Variations in soil moisture content of the 0 to 6 and the 6 to 12 inch layers on homogeneous 1-acre plots in Arkansas, Colorado, Louisiana, Mississippi, New Mexico, and Wisconsin were evaluated on the Vicksburg Infiltration Project. For each week of sampling at each site and depth, the variance associated with a single sample, taken at random anywhere in the whole acre was computed. Variances were partitioned into between blocks (S_b^2), between plots within blocks (S_p^2), and within plots (S_w^2).

Proportion of total variance for the 8 sites averaged:

0 - 6 inch layer			6 - 12 inch layer		
S_b^2	S_p^2	S_w^2	S_b^2	S_p^2	S_w^2
Percent					
13	19	68	13	20	67

Average standard deviation for the acre ranged from 1.1 percent to 5.8 percent moisture content by weight for the 0 to 6 inch depth and from 1.4 percent to 4.1 percent moisture content by weight for the 6 to 12 inch depth.

ESTIMATES BASED ON METEOROLOGICAL FACTORS

Many methods based on meteorological factors have been devised to estimate soil moisture content. The approach developed by the Vicksburg Infiltration Project for predicting soil moisture accretion and depletion for given climatic conditions has proven quite reliable over a wide area in this country.

Thornthwaite's method for estimating potential evapo-transpiration provides an index of effective soil moisture. For example, at Pine Flat, the measured water content in the entire soil profile under blue grama on March 25, 1954, was 6.07 inches for a net over-winter gain of 3.56 inches. According to the potential evapo-transpiration graph the estimated water gain was 3.49 inches, in very close agreement with actual water gained.

SOIL EROSION

E. H. Palpant

I. Effects of erosion (wind)

Erosion is the displacement of the soil by wind and water in association with gravity. Wind erosion acts as a fanning mill and sifts soils into particle size components. Through this process there is a great loss in fertility in the residual material. In one example the material removed from the Texas and Oklahoma Panhandle and deposited in Missouri and Iowa contained 10 times the organic matter, 9 times the available nitrogen, and 19 times the phosphoric acid as the residual material from this area. This destructive action to the soil resource has a long standing record. Cities and civilizations have been destroyed. Examples of this can be found in ruined cities of Baalbek and Jerosh, Syria. There is an area of a million acres in northern Syria lying between Aleppa, Antioch and Hanna which exhibits soil erosion at its worst. The former "Promised Land" of Biblical Israel is now a barren land.

II. Effects of erosion (water)

The first effect of water or wind erosion is to reduce soil productivity and make plant growth more difficult. Also the forces of water erosion act to form deep channels. These channels may lower the water table making it more difficult for plants to obtain moisture and in some instances increasing the cost of lifting irrigation water from the channel. As the gradient becomes less the eroded material is redeposited. This deposition causes aggradation of the stream channel which in turn may waterlog the surrounding valley. Of even greater consequence, in some areas, is the threat of flood to areas of habitation. The sediment during high flows may be carried directly to reservoirs decreasing their capacity for water. Of all the difficulties that erosion produces, the worst effect is on the source area itself where a valuable basic resource may be lost forever.

III. Erodibility variables

The following are important factors causing soil to erode:

A. Climate
   (1) Rainfall
      (a) Amount
      (b) Intensity
      (c) Size of raindrops (velocity)

(2) Relative humidity (associated with rainfall effectiveness)

(3) Temperature (air and soil)

(4) Air movement (vertical wind gradient)

(5) Changes in all of the above climatic factors with time (long time weather cycles)

B. Topography
(1) Degree of slope (associated with velocity of runoff)

(2) Length of slope (velocity of water and time to pick up eroded material)

(3) Aspect (influence on local climate)

C. Vegetation
(1) Foliage properties (rainfall impact and interception)

(2) Root systems (soil modifying properties)

(3) Stems (modifying pattern and velocity of runoff)

D. Soils
(1) Texture (ease of transportability of particles)

(2) Structure (ease of transportability of particles)

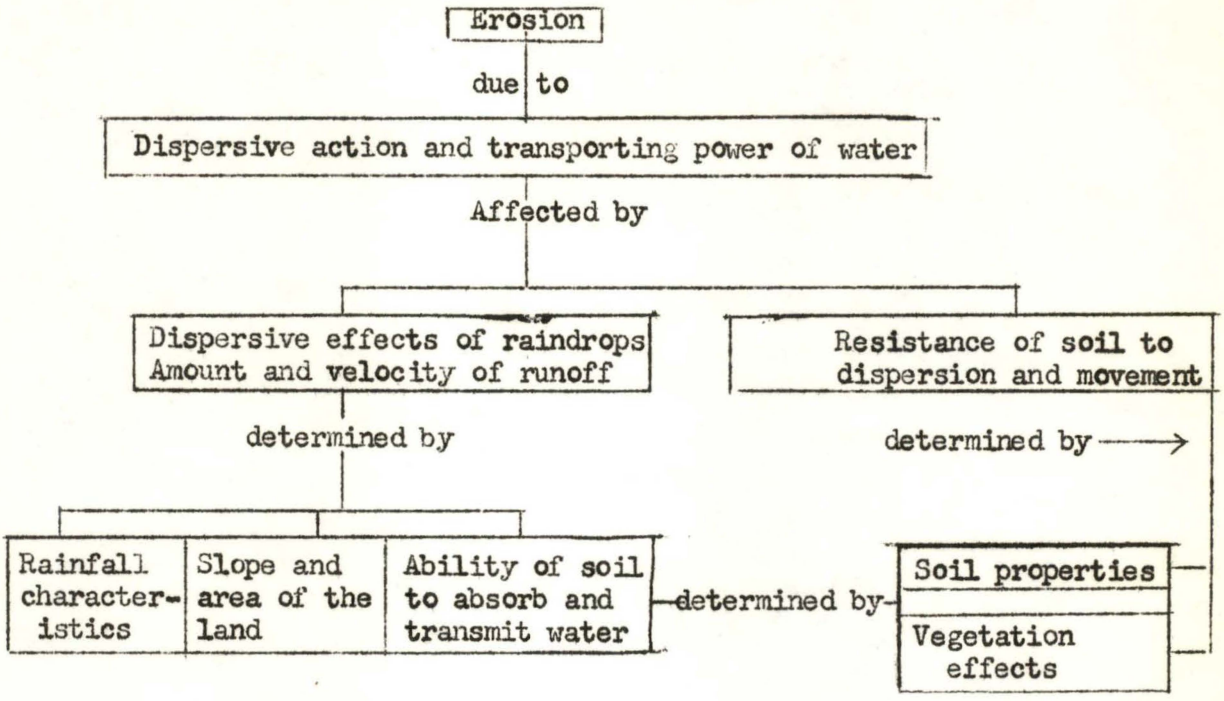
(3) Chemical properties (associated with structure and dispersability)

E. Human factor (affecting vegetation and soils)

IV. How water erodes soils

This process is long and complex but can be summarized by the following table found in "Soil Physics" by Baver.

Factors Affecting Soil Erosion Due to Water



V. How wind erodes soil

Wind eroded areas are characterized by:

1. Low soil moisture

2. Low relative humidities

3. High wind velocities

4. High temperatures

The above conditions may be artificially induced through poor management or occur naturally. Where these conditions occur naturally due to weather cycles (low precipitation periods) wind erosion may be serious since the time during these periods is not long enough to permit an adaptation of vegetation to the new environment.

When favorable soil climatic conditions occur for erosion, the wind acts as a fanning mill. Materials are graded out according to size, producing soils of uniform texture. Such textural qualities are not conducive to structural development. This is especially so with the coarser material. The dune sands are typical examples. Wind erosion is a common phenomenon in large areas of the West where precipitation is low. The result of low precipitation is soils with weak structural properties. When tillage or other soil disturbance exposes such soils to wind, the weak aggregates are broken up and reduced to particles small enough to become airborne. The air then acts as water when it transports sediment, but because of lower density it will not transport materials of as great a mass.

VI. Measurement of erosion

Some of the questions we may want to answer in dealing with erosion are:

1. Where does the material originate?

2. Where is it being deposited?

3. Under what conditions are aggradation and degradation occurring?

The following methods have been used to measure soil movement.

1. Profile station: This consists of well anchored reference posts which act as guides. A tape or wire is then stretched between the posts and vertical measurements taken at regular intervals to determine distance from the ground. Changes in these distances are a measure of soil material moved.

2. Runoff plot measurements: This method serves to obtain relative values of erosion. The Rocky Mountain Infiltrometer can be used for this purpose when obtaining infiltration rates. Larger plots are usually preferable especially of longer length, which more nearly approaches natural conditions.

3. Reservoir sedimentation surveys: (level measurements) This method gives quantitative data on erosion from a watershed. It can provide an overall or general answer to treatment effects on a watershed. It fails to show areas which are unstable or exactly the conditions where

erosion occurs. The data obtained from sediment surveys can be misleading if not corrected for compaction as new deposits are laid down. Also shrinkage must be taken into consideration if sediment is dry.

4. Sediment samplers: These devices are used to measure eroded material in suspension. The rising stage bottle sampler is a "one-shot" device for spot checking sediment loads. A well planned distribution of these samplers could provide information on source areas and amounts of material not deposited in areas where soil movement measurements are made. Some other sediment samplers are in the form of dividers, splitters or aliquot samplers. These devices are designed to accurately subdivide the total runoff into an easily measured sample.

5. Indicators: This category groups all methods which serve only to show that erosion is occurring or give only rough vertical measurements of soil losses.

   Plant crowns can be used but frost heaving and natural growth characteristics can be misleading.

   Gleason in California used bottle caps, washers held in place by large spikes, paint on rocks, etc. The bottle caps prevented erosion under the caps and therefore became miniature pillars as material eroded around it. The paint on rock method was to paint the rock portion next to the ground. Following the change of paint level to ground level indicated erosion. More in the realm of pure indicators are erosion pavements, stone capped pillars, gullies, and changes in color of soil profile.

6. New possibilities: The field of electronics is now offering many small electrical components which offer possibilities of obtaining reliable measurements of erosion and other phenomena in wild-land management research. Sensitive pressure transducers could possibly be used to measure changes in pressures associated with changes in sediment loads. Radioactive materials could be used to trace material movement. Devices presently designed to measure density possibly could be adapted to measure sediment loads.

VII. Erosion control

Erosion control has been practiced for thousands of years. Evidences can be found in the old Inca ruins in South America. Ruins of ancient civilization in North Africa and other areas also show evidences of erosion control. Perhaps no area has developed erosion control to the extent that the Chinese have. The terraced hillsides are well known to most people.

Erosion control in many ways is basically a waterspreading proposition. Vegetation serves to slow down and divide waters into many small rivulets rather than permitting concentration into large volumes which have powers to cut large gullies.

The following are methods employed in erosion control work:

1. Terracing - dividing sloping areas into level segments

2. Contouring - mounding earth on a contour creating a damming effect

3. Dams - check and detention types

4. Reforestation

5. Regrassing

6. Percolation - creating areas of high percolation

7. Mulching - good vegetation management creates a natural litter mulch but in addition the rock pavement mentioned previously acts as a mulch. Less familiar is the natural crumb mulch found on some clay soils. Artificial mulches such as straw, sawdust, etc., are at present not practical for large areas. A new material "Bitumuls soil cover" is presently being used with hay and straw to create a binding cover on road cuts. It offers possibilities for limited area application. A specially designed machine permits fast application.

8. Pitting - using eccentric or cutaway discs or a roller equipped with special retracting shoes.

9. Ripping or subsoiling

Consideration must also be given to stream bank stabilization since in most areas bank cutting is the major contributor of sediment to stream channels and reservoirs.

The methods used in any area will seek to do two main things:

1. Reduce rate of movement of surface waters to permit a longer period for water to enter the soil.

2. Keep or improve the soil surface conditions so that it will permit free entry of water.

VIII. Erosion control (wind)

Many of the practices listed previously will produce both water and wind erosion control. The following method, however, has been employed mainly for controlling wind erosion:

1. Shelterbelts - creating zones of calm air and reducing surface wind velocities.

2. Listing - reducing surface area exposed to high wind velocity and permitting eroded soil to be trapped in furrows.

3. Mulching - preventing high velocity winds from coming in contact with surface soils.

IX. Conclusion

Only the highlights of this subject can be covered in the time allotted; yet we often need to take a look at the gross aspect of a familiar subject to make sure our studies are as objective as they should be.

Challenges in erosion research may be summarized by the following:

1. Develop improved methods to measure or detect erosion.

2. Study other phenomena associated with soil erosion to better understand how erosion occurs.

3. Test new methods for erosion control.

Comments or questions:

Hardaway: Manning's formula answers the effect slope has on erosion. Also answers the effect of dividing flows by vegetation. Reducing velocity of flow with vegetation increases depth of flow.

Goodell: Less erosion associated with aggregation.

Frank & Osborne: North-facing slopes are steeper (due to erosion).

Hardaway: Vegetation condition is the answer (to change in slope due to aspect).

Used profile measurements to detect erosion in burned and unburned areas. Wanted to measure entire slope to find out whether soil just moved or left the area. This method probably the best measure of soil instability.

Dortignac: Could we find out where erosion was taking place by use of profiles? Answer: yes.

Rich: This method is heading toward obtaining total movement rather than a relative value.

Osborne: Suggested use of color stains to detect soil movement.

Goodell: Use chemistry to analyze source of sediments.

Rich: Are erosion indicators enough?

Palpant: That is answered in later part of the talk.

Dortignac: Objective in study at San Luis to find out how does soil move from slope to gullies.

Osborne: Are we interested in more than man's change of conditions leading to erosion?

Burke: Described series of small catchments distributed on slopes. Catches local transport.

Horton: Described San Dimas study where troughs were placed on contour and erosion material intercepted was evaluated on basis of distance from watershed boundary (length of slope or run).

Burke: Trench created water deficiency below.

Martinelli: Pedestalling in alpine area is a good measure of erosion by wind; also gravel pavement.

Dortignac: Wind erosion in New Mexico is underrated, particularly during drought periods.

Johnson: Snowdrifts have a block surface due to soil which shows soil erosion during winter.

Martinelli: Work of Zingg showed the size of particles that could be moved by wind.

Hoover: Transects will measure what has been moved out by wind.

Frank: We have a problem: The soil is moving. How much erosion shall we allow? Some technicians give too much attention to accuracy of measurement. We need to think in terms of end results. What it means. Let's concern outselves with research, not I & E. We need to back up and take a look at basic research.

Hardaway: How to stop erosion doesn't have to be developed by research but by administration except for principles. We need better liaison between research and administration. All erosion may not be as serious as we think. We need to adapt to it rather than cure. Money is not the answer to all the ills.

WATER RELATIONS OF TREES

J. P. Decker

The hydraulic system of the plant and water movement through the plant can be represented by a simple diagram consisting of two soil crystals, one root hair, one root epidermal cell, one tracheid and one mesophyll cell. Water evaporates from the mesophyll cell because the vapor pressure of water in the air is less than the vapor pressure of water on or in the mesophyll cell wall. Loss of water from the cell means that it now has a slight water deficit -- expressed best as a diffusion pressure deficit.[1/] Water moves to the cell from adjacent cells, from other cells to these cells, and so on down to the roots and root hairs. As the root hair develops a slight water deficit, water tends to move into it from surrounding soil.

Water tends to evaporate from the leaf as long as the internal atmosphere of the leaf has a greater DPD (diffusion pressure deficit) than does the mesophyll tissue. Water tends to move from soil to plant as long as plant DPD is larger than soil DPD.

Water in the soil is held between soil particles by capillary tension. As the soil dries out the volume of water held between particles decreases and the meniscus retreats into a smaller gap. Its radius decreases, and capillary tension increases. DPD of the water increases directly as the capillary tension (e.g., capillary tension of 10 atmospheres increases DPD 10 atmospheres). Thus a root hair with a DPD of 12 atmospheres would continue to absorb water from soil until the capillary tension of the soil water had increased to approximately 12 atmospheres. (not exactly 12 because salts in the soil solution also contribute to DPD, thus salts might be responsible for 2 and tension 10; total 12).

Thus movement of water from soil to plant to air (or under certain circumstances, from air to plant to soil) can be explained simply in terms of the common denominator of diffusion pressure deficit.

Actually the air-plant-soil system can be simplified even more. Water in the mesophyll at the gas-liquid interface probably occurs in the form of capillary menisci. When the radius of the average meniscus is less than the average meniscus in the soil, water moves from soil to plant. When they are equal, water does not move.

This is intended as a simplifying first-approximation. Let's see now how well it fits and where it isn't adequate.

1/ The diffusion pressure deficit is a unifying concept that is developed in detail in Meyer and Anderson's textbook of plant physiology.

Consider the effect of light on transpiration. In general transpiration increases with light and decreases sharply in darkness. How does it work? The stomata tend to open in light and close in darkness. When stomata are closed, the outward diffusion of water vapor from the leaf stops, the internal atmosphere becomes saturated and evaporation ceases. The second influence of light is on leaf temperature. Increased light means increased leaf temperature and increased transpiration.

The influence of air temperature is simple and straightforward. It operates through its effect on vapor pressure deficit.

The influence of humidity is simple and comes out exactly as one might predict.

The influence of wind is not so simple. Increased wind can have an accelerating effect by blowing away high humidity air that accumulates near the evaporating surface. In bright light it can decelerate transpiration by aircooling the leaf back down to air temperature. Some leaves seemingly have their stomata shaken shut by strong winds. (Hoover raised the question of whether quaking aspen was so affected. Decker stated that this information was not available but if he were ever to investigate the problem of wind-closure, quaking aspen would certainly be one of the first species selected).

The soil can influence transpiration in a number of ways:

1. Soil moisture -- this is obvious and straightforward if not in excess, that is, the less soil moisture the less transpiration.

2. Soil temperature -- with decreasing temperature the viscosity of water increases and its resistance to absorption increases; also the ability of a root to absorb and translocate water diminishes.

3. Concentration of soil solution -- the DPD of the soil solution increases with salt concentration and this tends to decrease absorption.

4. Soil aeration -- in general, absorption can be decreased with decreased aeration. This results from an effect on the protoplasm of root cells and appears to result more from CO_2 accumulation than from O_2 deficiency. Aeration can be decreased by soil compaction and by flooding.

The following points of information were established through comments, questions, etc.:

1. Soil particles are covered with a thin and tightly held film of liquid water.

2. Water can move from air to plant to soil depending on the vapor pressure gradient.

3. Considerable movement of water through soil atmosphere occurs by simple distillation.

4. Osmotic pressure of certain range plants is higher when grazed than when not grazed.

5. A plant wilts because of loss of structural strength to resist force of gravity. Its structural strength depends (degree of dependence varies with species and individuals) on internal hydrostatic pressure or turgor pressure (mechanism comparable to an inflated football). Hydrostatic pressure depends on water content. When a plant's transpiration has exceeded its absorption by a large enough amount to reduce the moisture content to the critical point, the plant begins to sag (wilt).

6. The roots of upland plants can be damaged or killed by flooding. Some are able to survive, however. Species differ in this ability to develop flood-tolerant roots.

7. A girdled tree dies because the girdling removes the phloem -- interrupts conduction of food to the roots. The roots starve and cease absorbing water. Crown probably dies of desiccation -- perhaps years later.

8. Older, suberized roots are able to absorb water.

ECOLOGY

Jerome S. Horton

Ecology is such a large subject that the remarks were held to a discussion of basic concepts of value in land and watershed management and to a few specific points of application.

Ecology can be roughly defined as the relation of plants to environment. Discussion was limited to the vegetation cover as a whole rather than specific reactions of the individual plant.

I. The first concept is that vegetation is dynamic and ever-changing. Climax (defined as the most mesophytic vegetation a region or site can support) is a handy tool for discussion. In some areas an apparent climax is reached but climatic events (such as strong winds) or maturing of the dominant individuals may mean a striking change to a different vegetation type.

II. Natural vegetation changes are brought about by creation of conditions (often only in a very small part of the area) favorable for growth and development of new individuals. Which species will become established depends upon needs of a particular species for:

   A. Reproduction and germination
   B. Seedling survival
   C. Mature growth

   If the environment of the site where a seed falls does not meet the basic needs of the species, no individual will develop.

III. Changes in vegetation brought about by man will create new conditions and new species can establish themselves.

In reference to the points in the original agenda:

I. Plant succession in relation to soil moisture.

   There are two aspects:

   A. As succession affects soil moisture. Changes in water loss rate as a sere progresses toward a climax are often difficult to measure. The Vicksburg data on soil moisture depletion showed no significance (in the surface foot of soil) between any plant types, whether weeds, grass, brush, or forest. Measurement of soil moisture in deeper layers could easily change the relationships. In the discussion that followed, the importance of measurements throughout the root zone was stressed. Bare soil was significantly different from vegetated soil but only slightly so.

B. Soil moisture as it affects succession

This point was considered as obvious, but several items were mentioned.

(1) Species vary as to amount of water needed for germination. For instance, tamarisk seeds germinate in saturated soils and therefore appear to become established only where free water is present.

(2) Growth of seedlings and young plants is likewise correlated to amount of available water.

II. Use of water in relation to plant density, species composition, and arrangement of foliage

Many of these points have already been discussed. The California lysimeter results were discussed as showing that there is a difference between species as to transpiration rates.

III. Management of vegetation

What practical changes can be made to change water use?

There are various ways of manipulating vegetation which could theoretically change water use.

A. Changing to a cover composed of shallower rooted species. This could be a change from a tree or shrub cover to a grass cover (see the California runoff plot study--California Forest and Range Experiment Station Annual Report for 1953) or to trees or shrubs shallower than present cover. The California chaparral root study showed that species which characteristically sprout after fire, such as shrub oak, will send roots in rock cracks as deep as 20 or 25 feet. The species whose individuals are killed outright in fires and regenerate by seedlings appear to have much shallower roots.

B. Changing to species with lower transpiration rate. Soil moisture losses from the California lysimeters show that scrub oak has a slower transpiration rate than pine and also that it transpires but little in the winter. Pine, on the other hand, depletes soil moisture whenever it is available in the winter (California Forest and Range Experiment Station Annual Report for 1956).

C. Change to grass cover, such as done on the San Dimas Experimental Forest, is difficult to maintain as deep-rooted forbs will invade and thrive on the moisture left in the lower soil layers. This point was emphasized by several. In conversions of any kind we should know what successions will take place. In many cases the shift may nullify any desirable effect of manipulation. The danger of reinvasion was discussed in the problem of phreatophyte control. Removal of tamarisk or

any other water-loving species would not be permanent because of the rapid spread of plants into these wet sites which have excellent conditions for germination.

IV. Watershed experiments

A. In Y-Canyon, San Bernardino Mountains, southern California, a comparison of a flood-denuded canyon and a natural alder-lined stream was made. Water losses (evaporation) from the denuded canyon were quite close to the natural stream (evapo-transpiration) during the first summer after the flood. During the next 2 summers the alders were growing rapidly along the stream in the flood-denuded canyon. Water losses appeared somewhat lower in the denuded canyon because evaporation losses were reduced by the shading caused by the young alders. In the fourth year, with a thick growth of alders in the denuded canyon evapo-transpiration losses in the two canyons were about the same.

B. In Fish Canyon of the Angeles National Forest a fire-denuded canyon maintained higher summer flows for several years than a comparative vegetated canyon. (Winter flood flows were very much greater from Fish Canyon due to high surface runoff from the burned slopes.) This increase could be explained, at least in part, to killing of the riparian vegetation in Fish Canyon. It was also suggested that sealing of seams in the bedrock under the stream channel by the winter mud flows may have reduced channel leaks and increased summer flows.

At this time there was much discussion on effect of burning upon subsequent plant growth. Many instances of increased post-burn growth, particularly grasses or other sown plants, were cited. Increased moisture, released ash, and increased nitrogen were given as reasons. The increase of nitrogen was thoroughly discussed and even though it is hard to explain, the increase was reported in many studies. The lush growth usually drops back to a normal in 2 to 3 years.

Some discussion was made of the high increase after forest removal in the Rockies, for example, Fool Creek. Reduction of interception does not seem to explain all of the increase but no good alternate explanation was proposed.

SNOW HYDROLOGY

M. Martinelli, Jr.

I. Introduction

A. Avalanche experts primarily concerned with snow mechanics and how snow condition is affected by environment. Dick Stillman gave an interesting account of the climax avalanches this spring with emphasis on the big avalanche which caused two deaths on Berthoud Pass highway.

B. From hydrologist's viewpoint

Snow pack is important because it

(1) Stores winter precipitation for later runoff

(2) Supplies a major portion of year's streamflow

C. By way of a summary for snow
Snow is
(1) One of the whitest objects known (visible light)
(2) Radiates heat as a "black body" (infrared)
(3) A very poor conductor of heat (10,000 times poorer than copper)
(4) A substance that requires a lot of heat to melt
(Heat of fusion is 13 x that for lead
7 x that for iron)

II. Physics of the snow pack

A. Metamorphism of snow pack

(1) Snow is in a constant state of change
(a) in the air
(b) on the surface of the snow pack
(c) within the snow pack

(2) Factors affecting metamorphism from the standpoint of hydrology

(a) Heat exchange at

air-snow interface (radiation, convection, condensation)

snow-ground interface - relatively minor importance

(b) Movement of water within the pack
Liquid stage -- melt water and rain
Vapor stage -- in the trapped air

(c) Temperature gradient within the pack

(d) Pressure due to overburden

(e) Wind erosion

(3) Effects of these processes

(a) Change in crystal structure resulting in increased density and settlement

(b) Formation of ice planes, resulting in a decrease in permeability to air, water vapor, melt water

(c) Change in liquid water-holding capacity

(d) Change in temperature of pack

(4) Two types of metamorphism that take place within the snow pack

(a) Destructive metamorphism
Crystalline snow changes into rounded ice crystals. This is caused at least in part by sublimation from the tips of the crystals and redeposition in the interstices.
It is accelerated by temperatures near 0° C., pressures of the overburden

Results of destructive metamorphism -
greater density
settlement of snow cover

(b) Constructive metamorphism
Formation of new crystals within the pack
Caused by - vertical movement of water-vapor by the circulation of air within the pack

Accelerated by - steep temperature gradient from bottom to top of pack
Lack of ice layers

Results of constructive metamorphism
Large, cup-shaped, layered crystals that have very little cohesion (called depth hoar or sugar snow)

Physics of the snow pack (continued)

B. Permeability to light

(1) Visible and ultraviolet light are mostly reflected; long wave length (infrared) mostly absorbed.

(2) Rather consistent reports for new snow.
Miller found 79 percent reflected as winter's average in California.

(3) Albedo decreases with the age of the snow surface.

(4) Albedo changes are due to dirt and debris on surface, roughening of surface, and change in crystal structure as result of reorientation of crystals under vapor pressure gradient in snow.

(5) Spring albedos are lower than winter albedos. Often use 60 percent as lower limit for clean spring snow and 40 percent as a lower limit for dirty snow.

(6) The blue color often noticed in ski pole holes, etc., in fresh snow indicates that blue light penetrates the snow better than other colors.

(7) The high absorption rate of infrared radiation indicates that snow will emit these wave lengths rapidly.

(8) In summary -- during the day snow reflects much of the incident solar radiation; at night, it radiates long wave length energy. Both act to cool the snow surface.

(9) Snow is a poor conductor of heat (good insulator); hence the cooling doesn't extend far into the snow pack. This means the air next to snow is cooled and a steep gradient established.

C. Radiation effects (Σ)

(1) On a horizontal surface

$$\Sigma = S \sin h + D + G - R - T$$

Where Σ = Sum of radiation received by snow
S = Vertical solar radiation
h = Altitude of sun
D = Scattered sky radiation
G = Long-wave radiation from clouds
R = Short wave reflected from snow
T = Long wave radiated by snow during day

Physics of snow pack (continued)

C. Radiation effects (continued)

(2) Clouds may reflect long wave radiation that has been emitted from snow or earth. This can bounce back and forth several times.

(3) Of the radiation that gets through the snow surface
50 percent gets down 10 cm.
10 percent gets down 30 cm.

(4) This is why the snow over stones, twigs, etc., buried in the snow pack melts first and exposes these items before the surrounding snow has melted an equal amount.

(5) Snow radiates in the infrared bands as a "black body" or as a"perfect radiator." It has an emissivity of 0.995 compared to 0.95 to 0.96 for vegetation.

(6) The pitted surface of the snow improves radiating ability.

(7) The rapid cooling of the snow surface means it radiates less rapidly as it cools.

(8) Actually, a grass surface loses about 2.2 times as much heat as a snow surface at the same time, since the surface of the grass doesn't cool as much.

(9) Long wave radiation (T) from snow is maximum on clear dry night

D. Thermal regime

(1) Winter conditions

(a) New snow is a good insulator (low conductivity) because of the large amount of air trapped in it.

(b) As density increases, insulating quality decreases.

(c) This means the middle of the snow pack is protected from cold air above and the warm ground below.

(d) Isotherms are crowded near the surface of the snow. At depth they are more divergent and at the ground surface temperatures very near 0° C. are found.

(e) Minimum temperatures were found at night and early morning at snow surface.

(f) Waves of cold move downward very slowly.

Physics of snow pack (D) Thermal regime (continued)

(g) Waves of warmth move downward faster but still not fast. Heat is transported downward by melt water.

(h) Diurnal temperature changes don't penetrate very deep into the pack.

(2) Snowmelt (spring conditions)

(a) Major change is the trend toward an isothermal snow pack.

(b) Melt water and in some cases rain penetrate the anisothermal pack and freeze in the cold layers.

(c) Freezing water releases heat that warms these layers.

(d) Additional insolation during the spring is also due to longer days, more direct radiation, and the trend for warmer air masses.

(e) No major runoff from the pack occurs until the pack becomes isothermal at 0° C.

(f) After pack becomes isothermal there is seldom any more freezing at depth. A surface crust of as much as 10 inches in Sierras does form at night due to surface cooling by long wave radiation. This crust releases appreciable heat to the air.

(g) Air temperatures in spring over snow drop fast until about 35° F; then much slower due to heat released by the freezing of ice crust and the inversion that isolates the lower layers from the atmosphere above.

(h) We need some index of the stage of metamorphism and the relation of this to the capacity of the snow pack to retain water against gravity.

Discussions

B. Frank asked if live barriers of trees couldn't be grown above the present timberline to reduce avalanche hazard. The opinion was that lodgepole pine might be helpful at certain places. Planting in the slide paths have to be made along the sides of the path and work out from there.

B. Frank asked if strip harvest cuts in the steep country where heavy snows are common might not cause avalanches. The opinion was that great care should be taken in such areas and that an uncut strip at least 1,000 feet wide should be left between any cutting and alpine areas above.

M. Hoover emphasized that many of the factors important for avalanche work such as wind movement, turbulence, and snow transport are important also in the snow studies at Fraser and the alpine snow work.

D. Hurd asked what the albedo of vegetation was. Albedo of vegetation is between 5 and 20 percent with an average of about 8 percent, whereas the albedo of snow is between 75 and 85 percent.

H. Brown asked if any work had been done to help estimate the energy balance for a watershed. The energy budget for a watershed has to be worked out by facets on the watershed. Tables have been developed for maximum radiation for given latitudes, slopes, and season by fire research. Some work on this subject has also been done by Becker at University of Wyoming.

E. Palpant asked if the pressure of the upper layers of snow was a factor on the snow pack. The effect of the overburden of the snow pack on the lower layers is not known, but it is thought to be a factor in metamorphism.

I. Sims asked about the importance of sublimation from the pack. Sublimation from the surface of the snow pack is no doubt a factor, but is not considered to be a major factor in the dissipation of the pack.

Nakaya has found liquid water on snow crystal at rather low temperatures, so the factor of evaporation from a liquid film cannot be discounted even at temperatures well below 0° C.

III. Measurement of snow pack

A. Snow depth

(1) Total depth on ground

(a) Usually a staff or stick mounted in the ground and graduated in inches, 0.1 of a foot, or cm.

(b) Location depends on objective of study

1. Small openings in forest for drift-free measures

2. Lee and windward slopes for drift measures

(2) New snow or storm depths

(a) Use snow boards or storm stakes--usually wooden; some ideas of using metal to reduce insulation.

Measurement of snow pack (A) Snow depth (continued)

(2) New snow or storm depths (continued)

(b) One placed at start of each storm and left until end of storm.

(c) Others placed each 4 to 6 hours during storm.

(d) Can determine settlement in new snow and in old snow from these readings:

Gross new snow = 2 + 5 + 3 = 10"

Net new snow = 8"

2" settlement new snow

B. Density

(1) Average in the vertical

(a) Vertical coring auger. Mt. Rose gets a core of snow which can be weighed:

Weight-ounces = inches

depth of water: $\frac{\text{Water depth}}{\text{snow depth}} \times 100 = \rho$ percent.

(b) Pits and sample cylinders-- this allows us to get density by layers.

(2) For new snow

Use snow boards and cut sample with cylinder (smaller diameter precipitation cans, etc.)

(a) -- Most commonly used. Melt snow and measure depth of H_2O and compare to depth snow.

(b) Weigh sample of known volume (Mt. Rose).

C. Water equivalent

(1) The amount of water produced by melting the snow

(2) This is the primary feature of the pack from a hydrologic standpoint.

(3) The simplest way to get this is to weigh snow surface-to-ground samples.

(4) Several possibilities for more elaborate rigs:

(a) Radioactive cobalt, etc., buried in ground and monitored from above.

(b) Gamma ray or neutron devices

(c) Electric devices depending on resistance or capacitance (hard to get good contacts)

Measurement of snow pack (continued)

D. Cold content (q); total cold content (Q)

(1) Appears to be very important from a hydrologic standpoint-- helps determine when runoff will start.

(2) Definition

q = number of calories needed to bring a column of snow 1 cm^2 to 0° C. and not melt the snow.

$$q = \bar{d}\, H\, \Delta\bar{t}\, c$$

Where $\bar{d}$ = snow density
H = depth snow in cm.
Δt = difference between snow temperature and 0° C.
c = specific heat of ice

Q = number of calories needed to convert a column of snow 1 cm^2 to water at 0° C.

$$Q = \bar{d}\, H\, (80 + \Delta\bar{t}\, c)$$

(3) For example:

	Calories q	Calories Q
1 gram of H_2O at 0° C.	--	0
1 gram of snow at 0° C.	0	80
100 cm. snow at -3° C; $\bar{d}$ .30 (30 grams snow at -3° C.)	45	2,445

(4) q is greater toward end of the winter than earlier because $\bar{d}$ usually is larger then and so is H.

(5) Usual way is to get q is to measure t at each 10 cm. and to take 50 cm. cylinder to get vertical samples for mass of snow.

E. Temperatures

(1) Mercury-in-glass or bimetallic

Require pits -- Place thermometer in at either uniform spacing or in layers of special interest

(2) Thermistor rigs
Can be buried in snow as pack builds up
Give continuous readings
Hard to know elevation of the unit due to settlement
Hard to put the device in so mast etc. don't interfere with snow deposition

Measurement of snow pack (E) Temperatures (continued)

(3) Possible to get temperatures from Mt. Rose sample by inserting thermometer through slots in side of tube

(4) This feature is seldom measured for hydrologic surveys but it is <u>important</u>.

F. Others

(1) Free water content or snow quality

Amount of liquid water in snow
Important in spring since this doesn't require the 80 calories/gm of heat needed to melt snow

Measured by
(a) Calorimetric methods
Thermos bottle. Hot H_2O or
(b) Centrifugal method

(2) Albedo
Reflectivity of visible light from snow surface
Often measured with photoelectric light meter or Epply pyrheliometer.

Discussion

Measurements

Hubert Burke asked about using a penetrometer for measurement of water content. It was concluded this instrument was probably most useful only to check hardness of a surface or the relative density.

FOREST INFLUENCES ON SNOW HYDROLOGY

B. C. Goodell

Forest effects may be broken down into: (1) Mechanical one of snow interception, (2) effect on energy received by snow.

Interception

Forest canopy intercepts snow, part is detained only, part retained. Part of detained portion may vaporize if dispersed by wind in transit to ground. At Fraser, nearly 0.6 cubic foot water in form of snow caught by 12-foot spruce during snowfall of 0.41 inch of water. Of this, half firmly held against severe shaking.

Intercepted snow presents very much greater surface per unit mass than does snow in the pack and is exposed in general to more wind and solar radiation.

Energy balance

Snow receives energy by three ways: Radiation, convection, condensation. Radiation most important source. Forest acts as efficient trap for radiation. Radiation so trapped effective on intercepted snow as well as on snow pack. Energy balance pertinent to snow evaporation as well as melt.

Radiation trapped by forests serves to supply heat to encompassed openings. This plus direct sunlight received by openings may, in general, result in greater energy supply to snow in small openings than to snow under the forest. This may not be case on topographically shaded slopes. Here forest may speed melting and evaporation.

Forest stand of low density may be nearly as effective a heat trap as one considerably more dense. This is because depth of canopy comes more into play as density decreases.

Radiation reconnaissance needed to determine how energy balance is affected by forest condition and by interaction of forest condition with topography.

EXPERIMENTAL METHODS

Jacob L. Kovner

What is statistics?

Statistics is a body of methods for making wise decisions in the face of uncertainty. It is a branch of scientific method used in dealing with phenomena that can be described numerically, either by counts or by measurement. Statistics provides rational principles and techniques that tell when and how judgments can be made on the basis of partial information.

Four stages in scientific inquiry

1. Observation. The scientist observes what happens; he collects and studies facts relevant to his problem.

2. Hypothesis. To explain the facts observed, he formulates his "hunches" into a hypothesis or theory expressing the patterns he thinks he has detected in the data.

3. Prediction. From the hypothesis or theory, he makes deductions. These, if the theory is satisfactory, constitute new knowledge, not known empirically, but deduced from the theory. If the theory is to be of value, it must make possible such new knowledge. These new facts are usually called "predictions" not in the sense of foretelling history, but rather anticipating what will be seen if certain observations, not yet made, are made.

4. Verification. He collects new facts to test the predictions made from the theory. With this step the cycle starts all over again. If the theory is substantiated, it is put to more severe tests by making more specific or more far-reaching predictions from it and testing them; until ultimately some deviation is found requiring modification of the theory. If the theory is contradicted, a new hypothesis consistent with the larger number of facts now available is formulated and then tested by steps (3) and (4), and so on.

In actual scientific work these four stages are so intertwined that it would be hard to fit the history of any particular scientific investigation into such a rigid scheme.

Statistics is pertinent chiefly at the first and fourth stages, observation and verification, and to some extent at the second stage, formulating a hypothesis. The methods most important at the second stage, however, are primarily those of intuition, insight, imagination, and ingenuity.

Statistics is helpful in the first stage, observation, because it suggests what can most advantageously be observed, and how the

resulting observations can be interpreted. Not everything can be observed; it is necessary to be selective.

At the second stage, statistics helps to clarify, summarize, and present the results of observation in forms that are comprehensible and likely to be suggestive of fruitful hypotheses (descriptive statistics).

At the fourth stage of scientific method, hypotheses are considered verified to the extent that predictions deduced from them are borne out by later events. Sometimes, especially in the natural sciences, it is possible to speed up the testing of predictions by experimentation. Frequently, however, a prediction can be tested only by waiting to see whether it comes true; for example, some astronomical predictions forecast the course of events (history) and some medical predictions indicate what would happen to human beings under circumstances that can come about only through accident. Statistics is relevant in either situation, for the essential problem is to determine whether or not the new data observed are concordant with the prediction.

In checking a prediction with numerical data, it is crucial to realize that the data and the prediction can seldom be expected to agree exactly, even if the theory is correct. Discrepancies may arise simply because of chance circumstances ("experimental error") that are not inconsistent with the theory. Furthermore, many important theories of modern science are probabilistic or stochastic rather than deterministic, in that they do not predict precisely how each observation will turn out, but only what proportion of the observations will in the long run turn out in each of a number of possible ways. Genetic theories, for example, do not in general specify the characteristics of each individual offspring of a given parentage, but only the proportion in which certain different kinds of offspring will appear. Such theories, furthermore, do not specify the proportions for any one set of observations, but only the "long-run" proportions or probabilities. In comparing a set of observations with theory, the question to be considered is, therefore, "Is the discrepancy reasonably attributable to chance?" If the discrepancy can reasonably be attributed to chance, the theory is not contradicted, and there is no adequate reason to seek special "causes" to explain the discrepancy. If the discrepancy cannot reasonably be attributed to chance, it is appropriate to look for causes, that is, to modify the theory.

Modern statistical reasoning has given a definite meaning to the verification of a hypothesis. A hypothesis is verified --"tested"-- to the extent that the influence of chance in the evidence has been correctly interpreted. Statistical procedures have been evolved for measuring the risk of incorrect interpretation, objectively, in terms of numerical probabilities, or, to put it differently, for measuring the risks of erroneous conclusions.

The statistical method

The simpler inductive methods and the Deductive-Inductive Method can only be applied to phenomena that can be adequately analyzed and examined under sufficiently varied conditions or circumstances. But the requirements are not always satisfied. Many phenomena--meteorological, biological, medical, social, and economic -- are too complicated for adequate analysis, and are not observable under sufficiently varied or controlled conditions for the reliable application of these methods.

The Statistical Method is an attempt to deal with such complex and exceptionally difficult phenomena in a scientific manner. It has several distinguishable functions. Its first and main business is to tidy up vast masses of varied data or material so as to make them suitable for practical or scientific use.

Like other scientific methods, statistical method aims at the discovery of connections between natural phenomena. And it does so by a close study of their concurrences or sequences. Unlike the so-called method of simple enumeration, it notes and records carefully not only actual concurrences and sequences, but also exceptions; it makes observations over as large and varied a field as possible; and cautiously draws conclusions that will fit all the observed facts.

The observation of only a few cases of concurrence, or sequence, or concomitant variation, among certain phenomena, especially when the conditions are not under control, and the full circumstances are not known, makes it impossible to distinguish a causal connection between the phenomena from a casual coincidence between them. But the observation of a large number of cases over a wide and varied range of circumstances, an exact record of positive and negative cases, and of variations between series of instances, may justify a highly probable conclusion about a causal connection between the phenomena concerned.

The assumption on which the statistical method proceeds is this: If two phenomena, say A & B, are not really connected, then their concurrence (or sequence, or concomitant variation) is a mere coincidence. In that case, the concurrence, etc., of B with other things than A should, as a matter of probability, be about as frequent as with A. But if the concurrence etc., of B with A is appreciably greater than with things other than A, then the two are probably connected. Such greater concurrence of B with A than with non-A is called their correlation or association (according as the reference is to "variables," that is, things that can be present in various measurable magnitudes, or "attributes," that is, what can only be present or absent, what can be counted but not measured) and the main line of enquiry by means of statistical method, as an independent method of science, is into correlations and associations as clues to causal connections. The degree of such correlation or association may vary considerably, and is expressed by certain "coefficients." When it is complete we get a general law of the ordinary type

(if A, then B), if partial we get what is more especially called a statistical law stating that B occurs in such and such a percentage of cases of A, or A = c (B), where c stands for some ascertained constant.

There was a time, for instance, when statistical records were kept of solar and lunar eclipses, just as they are still kept of meteorological phenomena. These records were useful and valuable, for they enabled the ancients already to note certain empirical cycles on which they could base fairly accurate anticipations of eclipses; although they did not understand them. But since the laws of the occurrences of eclipses have been discovered there is no further need of statistical records of them-- they can be foretold with accuracy and confidence. This, of course, does not affect the great value of statistical method as one of the methods of science, and as an auxiliary to the others. The important thing to bear in mind is that no amount of statistical technique can serve as an adequate substitute for a direct knowledge of, and familiarity with the phenomena under investigation.

From Encyclopedia Britannica

Samples and populations

Sample is often referred to as "the data" or "the observation" numbers that have been observed.

The population is the totality of all possible observations of the same kind.

(1) Sample results vary by chance.
(2) The pattern of chance variation depends on the population.

The basic problem is that a sample is not a miniature replica of a population, so when decisions about a population are based on a sample, it is necessary to make allowance for the role of chance in determining the characteristics of the particular sample that is available. The basic tool is the knowledge of the patterns of sampling variability that result from various populations, and therefore of the probability of getting the observed sample from any of the different populations which might conceivably have been its source.

Meaning of randomness

Randomness is a property not of an individual sample but of the process of sampling. A sample of size n is said to be a random sample if it was obtained by a process which gave each possible combination of n items in the population the same chance of being the sample actually drawn.

Randomness is important in statistics primarily because if a sample is random, but not otherwise, the mathematical laws of probability are applicable and make it possible to know the patterns of sampling variability in terms of which the sample must be interpreted.

Probability sampling is used to describe any sampling process in which randomness enters at some stage in such a way that the laws of mathematical probability apply and provide the sampling distribution needed for interpreting a sample.

Experimental design

Artificial rainmaking.-- Overall objective of the research was"to obtain a more complete understanding of the fundamental physical processes which govern the formation of precipitation." The specific purpose of the part of the work reported here was to find out whether "seeding" cumulus clouds -- that is, injecting appropriate materials, in this case water -- causes the clouds to rain.

Many clouds had been treated in many ways, but relatively little was known about what would have happened to them without treatment.

In the present experiment, clouds were seeded by airplanes specially equipped with radar and photographic equipment, meteorological instruments, recording systems, and so on. Occurrence of rain was detected by appearance of echo on a radar screen. Radar can tell whether cloud produces precipitation, but not how much or whether any reaches ground. Thus, even if it could be shown that seeding initiated precipitation, it could not be known whether the seeding had simply altered the timing of precipitation that would have occurred later anyway, or whether it had increased the total amount of precipitation. Attention of experiment was focused on initiation of precipitation.

The main statistical problem was to devise a method of deciding whether precipitation would have occurred in the absence of seeding. Obviously a control group of unseeded clouds would be required. It was essential, of course, that random selection be used in deciding which clouds were to be seeded and which were not. The main problem was to decide whether the proportion of seeded clouds producing rain differed from the proportion of unseeded clouds producing rain by a larger amount than could be ascribed reasonably to chance factors.

Each pair of clouds was made a separate small experiment. One cloud of each pair, selected at random would be seeded. The two clouds in each pair, having been chosen at nearly the same time from the same part of the sky, would tend to be more like each other in respect to the probability of rain in the absence of seeding than would clouds selected at different times or different places. (The alternative method would be to select two different groups of clouds without pairing.)

The chief problem of execution in the paired cloud design was to keep bias, conscious or unconscious, from entering into the selection of the cloud to be seeded in each pair.

"After a cloud had been selected for study, the senior scientist, acting as flight controller, instructed the meteorological-instrument engineer to release the treating reagent on the next pass. The cloud was treated or not treated, depending upon further instructions available only to the meteorological-instrument engineer. The senior scientist who selected the clouds for study was physically isolated from other scientists and had no knowledge of which clouds were treated until after each mission was completed. Whether or not the cloud was treated, observations and measurements continued until it had dissipated, developed into a well-defined rainstorm, or lost its identity by merging with other clouds.

"The meteorological-instrument engineer opened a sealed envelope and read instructions which told him whether or not to execute the order. These envelopes had been prepared earlier by the statisticians, who assured random selection by using a method equivalent to tossing a fair coin. It was essential that the man selecting the second cloud in each pair not know whether or not the first cloud had been treated. Had he known, for example, that the first cloud had been treated he might unconsciously have tended to pick a less (or more) juicy looking cloud for the next pass. A systematic factor would have then worked for or against the treated clouds; this would have invalidated subsequent analysis based on the assumption that treated and untreated clouds differed only by chance.

"The only conceivable way in which the controller might have known whether or not a cloud was treated was through the possible effect of the treatment on the behavior of the plane. When treating with water from the large valve, the decrease in load on the plane caused the plane to rise about 40 feet in 14 seconds. This change was not detectable by controller in cloud or during plane maneuvers. The reason for this lay in the natural turbulence found in the cloud and in the preoccupation of the controller with other duties."

It appeared that an experiment of the scale permitted by available resources was large enough to give a reasonable prospect of informative results.

The most important results of the experiment are as follows:

32 valid pairs of clouds were studied using the small water valve. Caribbean area -- 10/53 - 2/54 and 10/54 - 11/54. The results are given in the table below.

Untreated cloud of pair	Treated cloud of pair		
	Echo	No echo	Total
Echo	3	4	7
No echo	3	22	25
Total	6	26	32

Each unit in the table represents a pair of clouds; e.g., the number "4" in this table represents four pairs of clouds in each of which the untreated cloud produced an echo and the treated cloud did not. In the initial analysis only the data in the lower left and upper right entries were considered. The numbers in the other diagonal represent those pairs of clouds of which both members behaved the same, and thus do not contribute to a test of the hypothesis that treatment makes no difference on the average.

From the fact that in three pairs the treated cloud developed an echo whereas the untreated did not, and in four pairs the reverse was true, it is obvious that the experiment does not support the efficacy of the treatment. A chance division of the 7 pairs could not be more even than 3 and 4.

The meteorologists suspected that the reason for the lack of effect might be the smallness of the amount of water being released.

Results of tests for precipitation initiation in tropical cumulus clouds treated with water using large valve

Table (a)

Untreated cloud of pair	Treated cloud of pair	
	Echo	No echo
Echo	3	1
No echo	5	6

Table (b)

Untreated cloud of pair	Treated cloud of pair	
	Echo	No echo
Echo	2	5
No echo	12	12

Table (c) All data

Untreated cloud	Treated cloud	
	Echo	No echo
Echo	5	6
No echo	17	18

The probabilities of obtaining the results in the lower left-upper right diagonal (or more unusual results) under the hypothesis of no treatment effects as given in the above tables are 0.11, 0.072, 0.017, respectively. These probabilities were calculated under the assumption that large valve water treatment does not affect the average probability of precipitation initiation and are relevant if the alternative assumption under test is that water treatment increases the average probability of precipitation initiation. In designing this experiment, it had been decided that in problems of this type, 0.05 would be an acceptable level of significance. On this basis it must be concluded from table (c) that the null hypothesis, i.e., that treatment had no effect, is false and treated clouds had a higher probability of precipitation than untreated clouds. The probability of 0.017 given by the composite table must be viewed with some caution because it was calculated on the assumption that the total sample size was decided in advance, or at least decided on issues totally independent of what the initial results happened to be, whereas in fact this was not the case. It was decided to return to the Caribbean area after the data in table (a) were obtained. It is our opinion (and only an opinion since rigorous statistical techniques for this situation do not exist and since the rule for continuing experimentation was not made formal) that this will have little effect on the calculated probability. The experimental procedure and the types of clouds selected were the same during both seasons of operation.

While the logic of the basic statistical analysis is clear in this quotation it may be well to amplify it. In a group of paired tests those pairs in which both clouds performed identically tell us nothing about whether treated or untreated clouds are more likely to rain. We are interested, therefore, only in pairs in which one cloud rained and the other did not. In (a), for example, there were 6 such pairs. In 5 of these pairs the seeded cloud rained, in the 6th, the unseeded cloud rained. Now if seeding had no effect whatever, we would expect, except for chance, a 3-3 division rather than a 5-1 division. This situation is precisely analogous to an experiment with a coin. If you toss a fair coin 6 times, the most probable outcome is 3 heads and 3 tails. But chance alone will fairly often give 4-2 or 2-4. How unusual, then, is the 5-1 result or one more extreme that is 6-0, on the basis of chance alone. This turns out to be 0.11 or 11 percent, the figure given in the quotation.

Since 0.11 is a moderately small probability, we might suspect that 5 or more heads in 6 coin tosses was not due to chance alone, but to some inherent tendency for the coin to turn up heads more often than tails. Similarly when the scientists in the experiment were confronted with the data in table (a) they suspected that the treatment was actually having some effect. The suspicion was not very convincing but it did lead to a renewal of experimentation in the fall of 1954. That time the division was 12-5, somewhat more convincing, since the probability is only 0.072 by chance alone. The combined evidence of the two experiments suggests quite strongly that seeding was effective.

We have quoted also some of the qualifications necessary in interpreting the final probability of 0.017 that a result at least this favorable to the cloud seeding procedure could arise by chance alone. This basic qualification is that the result of table (a), the 5-1 split, was the first evidence of effectiveness given by the experiment. Earlier seeding efforts had given no hint whatever of success. Even though the experimental procedure had been modified prior to the 5-1 split, the experimenters could hardly put much confidence in this result alone. It is the evidence of table (b) that is most convincing. Table (a) is not irrelevant to the final conclusion, but after all an event of probability 0.11 may well occur among a set of events, just as 5 or more heads in 6 coin tosses is fairly likely to occur if a number of such tosses are made.

A closely related point is that the experiment probably would not have been continued, so would have had no opportunity to produce table (b) if just one cloud pair in table (a) had been switched. The fact that the second phase of the experiment was run at all, then, partly reflects good luck in the first phase.

From Wallis and Roberts, Statistics, A New Approach

Randomized cloud-seeding experiment

First randomized experiment conducted in the United States using ground generators of silver iodide. So far no clear-cut answer to the question of the efficacy of seeding is available, and none can be expected until a special, so-called "randomized" experiment is performed.

According to professional meteorologists not all storms are suitable for seedings and only a part of them are actually seeded. Also, in order to judge whether or not the seeding is effective, one must have some sort of standard of comparison, such as, for example, the amount of rain fallen from the same storm in a comparison area; presumably not affected by seeding. In these conditions, even if the comparison between the rain in the target and in the comparison areas appears favorable to the conclusion that seeding is beneficial, there is always the question of whether or not the observed excess of rain in the target is the effect of seeding or a mark of success in forecasting. In fact, the meteorologist engaged in cloud seeding may be expected to be able to identify among the approaching storms those that will deposit in the target relatively more rain than the others. Then, if only those more promising storms are seeded, the comparison with any preassigned standard would tend to indicate a positive effect of seeding even though the actual effect of this operation is minute or nil.

This difficulty of distinguishing between the success of forecasting and the success of seeding can be avoided by performing a randomized trial. The meteorologist engaged in weather modification is allowed to select at will the opportunities for seeding. Once such an opportunity is identified a random experiment is performed; for

example, a coin is tossed. If the coin falls heads then the actual cloud seeding begins, but not otherwise. However, the observations of rainfall are conducted on all seeding opportunities; both those seeded and those not seeded. Then with a sufficiently long series of observations, the comparison between the seeded and not seeded storms allows a definite conclusion, regarding the effectiveness of seeding as such, free from the possible effects of forecasting.

Science 11 Jan. 1957, Vol. 125, p. 61

Brief discussion of errors of first and second kind

In testing a hypothesis it is always necessary to specify in advance the alternative hypothesis. For example, the null hypothesis is usually stated and a critical region selected so that the risk of rejecting the null hypothesis when it is true is low, generally 1 chance in 20. If this alone constituted the test of significance of the experiment then it would not be necessary to conduct any experiments at all. It would be sufficient to decide the outcome of null hypotheses by spinning a wheel where the critical region had been marked off as 5 percent of the circumference. If the wheel came to rest in the critical region the null hypothesis would be rejected. In the long run, correct null hypothesis would be rejected only 5 percent of the time. Obviously the procedure is faulty in that a real effect would have very little chance of being discovered, in fact, only 1 chance in 20. In other words hypotheses alternative to the null hypothesis, that is, real effects should have a good chance of being discovered as a result of the experiment.

This leads to the concept of errors of the first and second kind. Consider, for example, two related hypotheses such as a null hypothesis (H_1) and an alternative hypothesis (H_2). Then the results of the tests of significance of the experiment may lead to the following decisions:

1. H_1 is true and it is accepted.
2. H_2 is true and it is accepted.
3. H_1 is true but it is rejected (error of the first kind).
4. H_2 is true but it is rejected; that is, H_1 is accepted when it is false (error of the second kind).

Obviously (3) and (4) lead to incorrect decisions and in any statistical investigation certain risks are associated with each kind of error. Moreover the errors are antagonistic to the extent that the lower the risk for an error of the first kind the higher the risk for making an error of the second kind. Thus if we choose a critical region so that the risk of rejecting the null hypothesis when it is true (error of the first kind) is very low, say, 1 in 1,000, then the

chances of missing a real effect become very large. Ordinarily the error of the first kind is associated with the null hypothesis because as working scientists we want to reduce the chances of "discovering" real effects which, in fact, do not exist.

A good example concerns the basis of our legal system. Here the first hypothesis is that the defendant is innocent. The alternative hypothesis is that he is guilty. Then we can set up the following table of possible decisions by the jury.

	Reality (unknown)	
Decisions	Innocent	Guilty
Let go free	Correct decision	Incorrect decision (error of second kind)
Punishment	Incorrect decision (error of first kind)	Correct decision

Also in this case society has tried to devise ways to reduce the risk of an error of the first kind to a minimum in order to insure that an innocent person should not suffer whereas as a result the guilty frequently are set free.

In conducting experiments, therefore, it is important to specify the alternative hypothesis in advance and to decide on the relative risks for the two kinds of error. Then if certain information is available the size of the experiment can be determined in advance to meet these objectives.

Curve fitting

One aspect of curve fitting needs to be emphasized, namely, that the process of fitting a curve to observational data purely on an empirical basis does not ordinarily provide any information as to causal or underlying relationships between the variables. Only when some good logical basis for expecting a certain type of relation to hold should mathematical curves be employed in describing the relationship. In this case the constants of the equation serve as an explanation of the real nature of the relationship. In all other cases the free-hand curve gives as much information as the mathematical curve in describing the nature of the relationship, and is usually much easier to obtain. In many cases the arbitrary selection of a mathematical curve cannot provide as good a fit as a free-hand curve and many investigators are prone to attach virtues to such a mathematical curve which, in fact, do not exist.

Usually, however, an investigator with a knowledge of his subject is able to establish relationships between variables on a logical basis.

Expressed as a hypothesis, if the curve fits the data then verification has been achieved and a law may be said to have been discovered expressing the nature of the relationship between the variables.

Large-scale investigations

A method was presented at the meeting for handling a large number of observed variables in order to establish a relationship in the form of a mathematical curve. The analysis will be sent out under separate cover.

Curve fitting -- approximation methods

Reference was made to approximation methods for fitting curves. This subject is covered very completely in "Methods of Correlation Analysis," by M. Ezekiel, John Wiley and Sons, Inc., 2nd edition.

Also the method of coaxial plotting was mentioned as given in the appendix of "Applied Hydrology" by Linsley, Kohler, and Paulhus, McGraw-Hill.

WORKMAN CREEK WATERSHED STUDY

(Description and Plan of Experiment)

L. R. Rich

Workman Creek consists of a three-forked watershed of 1,087 acres draining westerly. Each fork is tapped by a perennial stream. The elevation ranges from 6,590 feet at the lower weir to 7,724 feet at Aztec Peak. Precipitation averages 31.6 inches annually and streamflow has averaged 3.10 inches from Middle Fork (521 acres), 3.29 inches from North Fork (248 acres), and 3.34 inches from South Fork (318 acres).

With three watersheds an opportunity was present to study effects of timber cutting or manipulations on two of the watersheds and using the third watershed for the climatic check. National Forest Administration requested that one treatment follow effects of Forest Service timber cutting on one watershed. Effects of different types of vegetation removal was decided on for the second watershed.

The objectives of this study are: (quoted from Working Plan)

1. To determine by progressive steps of vegetation eradication how the different kinds and amounts of vegetation influence water production (North Fork).

2. To evaluate timber management practices directed toward high production of water and wood and to determine what influence timber removal and the accompanying logging and road-building operations have on the increase of sediment (South Fork).

It was assumed that enough studies had been completed (Wagon Wheel Gap, Coweeta, Fish Creek) that indicated drastic treatments do increase water. This study was set up to see how less drastic treatments affect water yields and accompanying sediment production.

The pretreatment data however, indicated sizable increases would be required for statistical significance, varying from 0.55 inch for 5 years and 0.26 inch for 12 years if South Fork were treated and North Fork held as the climatic check, to 1.30 inches for 5 years and 0.62 inch if Middle Fork were treated and North Fork held as the climatic check.

Four treatments to determine effect of vegetation removal on North Fork were:

A. Cutting water-loving vegetation (alder and maple)
B. Cutting wet-site vegetation (fir in creek bottom)
C. Cutting moist-site vegetation (areas dominantly fir)
D. Cutting remaining vegetation (dry-site vegetation)

Two treatments to determine effect of timber harvest on South Fork were:

A. Remove approximately 35 percent of the basal area by harvesting 40-50 percent of the merchantable timber plus silvicultural improvements such as mistletoe control, oak removal, and favoring pine in the pine-fir transition to get the desired 35 percent basal area reduction .

B. Remove an additional 25 percent of the merchantable volume with additional thinning and removing remaining mistletoe infection to reduce stand density to the minimum for good timber production (80-100 square feet per acre).

Treatment A has been completed on North Fork (August 1953) but no significant difference has been picked up from the small cut (0.6 percent of the basal area on the watershed). This was anticipated during design of treatments, but the feeling persisted that it would be worthwhile to test a riparian cut even though significance were not obtained. Since greatest effect should occur during low summer flow, the drought years should test the treatment and it is probably time to go on to the next treatment.

Treatment A has been completed on South Fork. Timber harvest removed 50 percent of the merchantable volume,which was almost exactly 3 million board feet from the 318-acre watershed. This reduced basal area about 24 percent, skid trails and roads another 6 percent, and improvement cutting (mistletoe control, oak poisoning in ponderosa pine, and fir removal in the pine-fir transition) another 6 percent to a total of about 36 percent. This was spread over parts of 4 years (started June 1953 and completed in July 1956). This may have eliminated the shock treatment and allowed nature to start reoccupying the site as the cutting progressed.

The experiment was set up for analysis by Wilm's covariance which compares streamflow from the treated and check watershed but eliminates rainfall, and assumes that rainfall is similar on all treated and check watersheds.

Supplemental studies include:

1. Sediment is measured by weekly samples (turbidity) at the weir sites, which have run from 4 to 66 p.p.m.,except one sample after a summer storm of 1.25 inches was as high as 125 p.p.m. Heavy sediment is caught and measured in the weir ponds.

2. Erosion cross sections have been established, 3 randomly located in each 600 feet of channel and along the road, and a profile in the timber plots (nails in trees with a tape stretched between and measurements to the soil surface).

3. Interception has been measured in both pine and fir stands.

4. Foliage weights and surfaces have been sampled.

5. Eight soil moisture stations are in the area.

Even though no significance has resulted from the riparian cut on North Fork, the data are perhaps valuable in showing that only small changes in water follow small changes in vegetation, which may indicate that drastic changes are required to obtain large increases in water yield.

The first year's data after completion of the complete cut on South Fork will be available September 30, 1957. Partial cuts have shown no significance. The period, however, has been below average in precipitation and it is probable that an average year that will satisfy the soil moisture deficit will be required to make an adequate test of the treatment.

Discussion brought out the following points:

1. Rainfall runoff relationship is not as good for testing treatment as runoff relationships between check and treated watershed.

2. The study is not a random sample but is o.k. for drawing inferences. Extrapolation would be difficult and should be used with caution.

3. Precipitation on each watershed is not available prior to 1943 and has not been used to improve the estimating equation.

4. Because of different ratios between high and low flow during the year, monthly correlations are not as good as annual and seasonal correlations.

5. Drought years may not show increases that could appear in average or wet years.

6. Riparian cut should show up in drought years.

7. Time trends should be watched; none have been observed.

8. If the alder growth had not been faster than fir, it may be growing as an understory to the fir or started as suppressed individuals.

9. Treatment on South Fork may not be drastic enough to obtain significance.

10. Plots with drastic treatments should be established.

11. Colman's book stresses the fact that watershed treatments have been drastic and there is need for study of intermediate treatments.

12. It may or may not be desirable to study effects of K-V timber cutting practices even though those applied on South Fork are an estimate of methods 10-20 years in advance.

13. Trends from this study are only data from a nonrandom watershed study. Is it possible that a similar study on Castle Creek, 100 miles away, will help project the data?

14. Region does not consider Workman Creek typical. As yet they pay no attention to research findings but water findings will influence their thinking in view of the Barr report. More watersheds are needed.

15. Workman Creek was once considered for abandonment, but it was decided to continue the experiment.

16. Region needs inventory data such as where water comes from and how to increase it.

After the question of when the next treatment on North Fork was to be started, the proposed plan to combine treatments 2 and 3, the wet and moist site treatments, was presented. Combining these two treatments into a single treatment would maintain the basic objective of the study "To determine how different kinds and amounts of vegetation influence water yields by removing the vegetation on the watershed according to vegetation types", because both the remaining wet-site vegetation and the moist-site vegetation are dominantly fir.

A 15-percent increase in water yield is required to obtain significant results in 12 years. A 15-percent increase is equivalent to approximately 1/2 inch over the watershed or 10 acre-feet. If the second treatment (wet site) includes 100 feet on each side of the 3,300-foot main channel, it would amount to about 15 acres and 10 acre-feet from 15 acres would require 8 inches increase over the treated area. This is more than double the average yield from the watershed and seems out of reason. If the wet and moist site treatments were combined, the area would be about 60 acres, Ten acre-feet from 60 acres would require about 2 inches, which may be possible.

This treatment should speed up the experiment and localize effects. This is a point that is important in a drought and wet series, because a treatment may not show up in drought years but may add to a subsequent treatment during wet years.

Discussion brought out the following points:

1. Length of time since calibration is not serious if shifts in trends are considered.

2. Infrequent wet years may cause different results; consequently it is desirable to reduce number of treatments.

3. The limited nature of what could be derived from the study points to the desirability of not masking treatments.

4. Compared to Fool Creek, small water yield increases require a long time for significance.

5. Care must be observed in describing the negative results from the study.

RESEARCH OPPORTUNITIES

M. D. Hoover

I am pleased beyond expectation with the fine presentations of the topics and the stimulating discussions. Certainly, we are more aware than before of the opportunities to contribute knowledge.

Fine progress has been made but there is still much to do. We must guard against a tendency to repeat. Once we've learned how to do something, such as run an infiltrometer or calibrate a set of watersheds, there's a temptation to keep on doing it without much thought of purpose. Sometimes this has put us in a rut from which escape is not easy.

The need to demonstrate that changes on a watershed can influence streamflow may be past. There seems no need to show that overgrazing causes more sediment, that poorly located logging roads cause erosion, or that cutting all the trees increases water yield (for a while anyway). What we need now is the kind of information that can be applied to answer a question such as this:

More water is desired from X watershed which has soils derived from granite, Douglas-fir on north slopes, open ponderosa pine and grass on south slopes, with willows along the stream. Precipitation is Z inches, with so much each month and extremes of such and such. Monthly mean and extreme temperatures are given. Soil depth and kind are mapped. What changes in vegetation and management can be done in the various situations to improve water yield? Answers should give species of grass to be favored, density of trees and similar definite prescriptions so that suggestions can be put into practice.

We now have an opportunity to get down to more basic studies. National Forest Resource Management and various public and private groups are putting in demonstration watersheds and doing other things to get orientation and preliminary guidance information. This is definitely not competition with research but a big help, and we must learn what we can from their efforts. We don't have to duplicate their work and can pursue investigations that will give better answers to future questions.

The question of planning work to give answers when needed is important. An experiment designed to give an answer 20 to 30 years from today should be viewed with suspicion. Will we need that answer when we finally have it? Are we just being lazy and trying to avoid hard thinking and hard work? Certainly, confirmation of some hypotheses may require many years but that is more testing than gaining new knowledge. Managing vegetation on watersheds to attain various objectives is what we must learn to do. This means we must learn more about individual species. How do species differ in rooting depth, season of water use, response to various soil and soil moisture situations, and in absorption of solar energy? What is

the effect of age, height, spacing, and arrangement of canopy on water use? How does grazing influence moisture use of various grass species?

This kind of information can come from well-planned and vigorously carried out fairly short-term studies. Let's see how fast we can learn instead of insisting it takes a long time. It will be a real satisfaction to get at least some of the answers ourselves. In any case, there will be plenty left for our grandchildren to learn.

The pressing "problems" of water supply should not divert us from obtaining knowledge. There are usually many ways to improve a water situation and our specialty doesn't include all possibilities. As we learn about the role of vegetation, that information will be available for use when and where needed. Very likely it will be applied to solve problems not now foreseen.

SERVICEWIDE WATERSHED RESEARCH PROGRAM

Bernard Frank

Herb Storey is sorry he could not attend this meeting. He has just returned from India. While there he realized the handicaps to scientific work there. Elementary devices and concepts, which we take for granted, are lacking. Taboos against manual work of any sort by technical people and cultural taboos delay progress. Professional journals are not easily obtained. We are more fortunate than we realize.

Will touch on several aspects to give a background of the national setup, what we have in mind for the future, and how we might keep alert to our opportunities in this vital field of research.

1. Present organization

Now have watershed management research at all 9 stations and in Alaska. The budget for 1957 is $931,000 and expected to be a million dollars in F. Y. 1958. There are 33 research centers doing watershed research.

2. Ten-year program

The appendix of the national program has been circulated; therefore, will only describe briefly.

There are three major objectives of planned research.

a. Prevention of watershed damage
b. Restoration of damaged watersheds
c. Water yield improvement

Proposed work will require 200 man-years of technical time from several fields of science. It is believed that 58 percent of watershed researchers will be nonforesters by 1968.

Program more than the direct carrying out of the above objectives. The limitation of applied studies is fully recognized. Program provides for: (1) Improving basic knowledge of watershed processes through studies of ecology, soil biology, climate, etc.; (2) development of procedures for soil classification and mapping; and (3) devising methods for collecting hydrologic information on the national forests.

Cooperative team approach recognized to be of great value and provision made for joint projects with timber, economics, utilization, and range research.

These items discussed at RF&D meeting in Washington. The proceedings of this meeting will be sent to the field.

3. New work and line projects

A new framework of work and line projects has been developed as a direct outgrowth of the 10-year research program but also based on past field experience with the previous scheme. (Craddock of Intermountain station did most of the work on this.)

4. Watershed Management Research Division Chief Meeting and Watershed Management Conference of 1955

One important result was faster and more complete exchange of study prospectuses and work plans. Also more discussion and helpful criticism of procedures. Another result has been step-up of abstracts of articles from foreign literature.

I am serving as a FS representative on a Work Committee on Translation of Russian Scientific Literature. Committee has proposed to request translation of:

1. Abstract publications
2. Periodicals, texts, and special reports
3. Special items such as articles, bulletins, and books

5. Current trends

There is a growing interest in our work. This is shown by the increasing discussion of watershed research at meetings of the USDA Advisory Committees.

The Forest Research Advisory Committee has recommended more research in basic hydrology, extension of research to new areas, work on economic relations of watershed work, and on recreational aspects of watershed programs.

The Soils, Water, and Fertilizer Research Advisory Committee was formerly apathetic toward watershed work but now has lively discussions.

Conservation associations, civic, State, and industrial groups are providing financial and other material support to watershed programs and watershed research.

6. Expanding Federal action programs

Soil Bank, Watershed Protection and Flood Control, and National Forest Resource Management programs are placing increasing demands on research and are in a position to quickly apply research results.

7. Realism and science

People are more interested because they are worried. However, they expect miracles because science has seemingly done the impossible again and again. Even watershed research shares in the reputation thus built up. Because of this we had better closely examine past concepts, past accomplishments (or lack of them), and our thoughts and plans for the future.

Particularly we must remember that past conditions may be a poor guide to the future. Need to be alert to shifts in trends and recognize indicators of shifts to improve value of forecasts. Improved statistical methods will help but are not in themselves enough. Need to ask ourselves kinds of questions that will provide more fruitful leads to solutions.

HOW STATISTICIANS AID RESEARCH

J. G. Osborne[1/]

Statisticians in the Forest Service provide three main groups of services. These are (1) consultation, (2) training, and (3) statistical research.

Consultation in the planning and analysis of experiments is a big demand on available time but has proven beneficial both to the research program and to give statisticians an appreciation of field problems. The addition of statisticians to station staffs should provide more time for consulting services.

Training has been the big job and has taken the lion's share of available time. With the normal turnover as a result of retirement and transfer and the large jump in research personnel, it was impossible to give all the required training in a centralized course at Washington. The station statisticians have organized or are organizing courses which should satisfy immediate needs of research people.

Research in statistical techniques and the development of new methods designed for forest research needs is the challenging job. There has been too little time for this, yet it offers great hope. Most experimental designs are based on agricultural models and may not be as useful in forestry work.

The planning factors manual is an important job for all of us in the next year. Watershed researchers should be sure to send in pertinent material.

1/ This account is based on recollection and sketchy notes and Osborne, no doubt, reserves the right to deny any or all statements.

FOREST SERVICE RESEARCH

I. H. Sims[1/]

When the Committee on Research Establishment (CORE) was set up, Dr. Harper organized a committee in the Branch of Research on research 10 years ahead (CORTYA). The work of this committee culminated in the 10-year program for forest research. These jobs have taken considerable time but the results are extremely worthwhile.

A problem facing research, as well as industry, is a shortage of people in the 20-30 year age class. During the depression years, families were small and the shortage of depression babies is one reason for present problems in recruiting. This means we must learn how to use the folks we have effectively and avoid lost motion. Advanced training is important. It is a pleasure to report that Rocky Mountain station has the largest number of its personnel taking academic training during the past year. Perhaps even more is needed to fulfill requirements.

Federal agencies are trying to obtain legislation to send employees to school. Perhaps will pass. Almost everyone feels there should be some strings on this to prevent abuses. This may mean student will have to defray part of his expenses or at least will receive less than full salary while at school. Just how most promising candidates can be selected without discouraging others will be a problem.

It is a tremendous task to coordinate research work within the Department. The Central Project Office is set up to assist in this. The new line and work project system in the Forest Service will bring us more nearly in line with other Department agencies.

1/ Based on memory and notes.

LIST OF THOSE ATTENDING ALL OR PART OF WATERSHED RESEARCH MEETING
FOR ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION PERSONNEL
Manitou Experimental Forest May 6-10, 1957

Name	Location
Aldon, Earl F.	Flagstaff, Arizona
Berndt, H. W.	Manitou Experimental Forest
Brown, Harry E.	Grand Junction, Colorado
Burke, H. D.	Vicksburg, Mississippi
Curtis, W. R.	Flagstaff, Arizona
Decker, John	Tempe, Arizona
Dortignac, E. J.	Albuquerque, New Mexico
Frank, Bernard	Washington, D. C.
Gary, Howard L.	Tempe, Arizona
Gibbons, Robert D.	Manitou Experimental Forest
Goodell, B. C.	Fort Collins, Colorado
Hardaway, George D.	Albuquerque, New Mexico
Hoover, M. D.	Fort Collins, Colorado
Horton, J. S.	Tempe, Arizona
Hurd, Richard M.	Rapid City, South Dakota
Johnson, W. M.	Laramie, Wyoming
Kovner, J. L.	Fort Collins, Colorado
Lamb, Alan J.	Holbrook, Arizona
Love, L. D.	Fort Collins, Colorado
Martin, S. Clark	Tucson, Arizona
McNutt, Jack F.	Denver, Colorado
Osborne, J. G.	Washington, D. C.
Orr, Howard K.	Rapid City, South Dakota
Palpant, E. H.	Albuquerque, New Mexico
Price, Raymond	Fort Collins, Colorado
Reynolds, H. G.	Tempe, Arizona
Rich, L. R.	Tempe, Arizona
Sims, I. H.	Washington, D. C.
Stillman, Richard M.	Idaho Springs, Colorado
Martinelli M.	Fort Collins, Colorado