Increasing Crop Potentials Through Water Availability[1]

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Water is essential for all life. It has probably had more influence on the development of man's history than any other resource. Agriculture, with its production of food and fiber, is especially dependent on water.

In this symposium we are concerned with maximizing Indiana agriculture. Water and its availability, however, knows no political boundaries, but is of national, and even of international interest.

Water and its availability is a broad subject. There is much discussion about agriculture's competition for water with industry, domestic use, power, navigation, and the host of other interests. There are many interesting facts about the physiological response of the plant to optimum water conditions, the economic aspects of water and agriculture, and a vast amount of statistics. These remarks, however, will be confined to the availability of Indiana's water resources.

We are all familiar with the hydrologic cycle. The sun is the over-all source of energy, while the ocean and land masses, rotation of the earth and other factors are responsible for our weather and rainfall patterns. It is a large scale system but an inefficient system in distribution both in time and space. The moist air masses moving from the Pacific Ocean eastward across the North American Continent go on from the East Coast with more than three-fourths of their original moisture. (Ackerman and Lof 1959). Further, it is estimated that even a heavy storm precipitates only 0.5 percent of the overhead moisture in the storm area. Indiana is favorably located in that its normal rainfall is more than adequate for all uses in the foreseeable future.

As with any circle, or cycle, there is no logical beginning or ending point. However, when the atmospheric moisture condenses and falls as rain, it no longer is a part of the large scale system, but becomes an integral part of a watershed. The Indiana Water Resources Study Committee (4), has defined 18 major Watersheds in Indiana for us in their 1956 report. They have taken the hydrologic data from the various sources and have made an analysis which is extremely valuable.

As soon as the rain falls on the watershed it can then be related to a hydrological equation; namely: $P = R.O + E_T + \Delta S + \Delta SMD + \Delta G + L$

Where

P = Precipitation
$R.O$ = Runoff
E_T = Evapotranspiration
S = Surface Storage
SMD = Soil Moisture Deficit
G = Ground water
L = Leakage from watershed

In this equation we have incoming water as precipitation and outgoing water as runoff and evapotranspiration. The surface storage, soil moisture deficit, and ground water include the storage within a watershed.

1. Contribution from Purdue University, Agriculture Experiment Station, Journal Paper No. 1835.

Adapting this equation to Indiana conditions we have from past records the annual mean precipitation of about 36 inches in the north and 42 inches in the south. This is the only source of water for the watershed, excepting possibly the extreme right hand term, Leakage. In some watersheds, water may move in or out through porous formations. Hydrologically this water is usually difficult to account for, and unless known to occur, it is assumed to be negligible.

Again, the physical forces of the atmosphere are responsible for the amount, intensity and location of precipitation (Ackerman and Lof 1959) (2). Weather modification studies have shown that cloud seeding has increased precipitation by 10-15% in orographic areas, which does not include Indiana. Meteorologists are continuing to improve their techniques in predicting precipitation and climatologists have been doing excellent work in developing probabilities of occurrence. The fact remains that to date, man has practically no control of rainfall occurrence.

Each of the terms of the right hand side of the equation has peculiar characteristics, but in turn the terms are related to each other. Runoff, R.O., has two component parts, namely, the surface and the groundwater. The surface runoff is water which does not infiltrate into the soil during a storm, but flows directly overland to the watershed outlet. This is the water which causes rise in stream and river flow, and frequently flooding. The ground water runoff is water contributed to the watershed outlet from the underground source. It is the source which keeps the stream or river at its base flow level. The total of these two is measured on a hydrograph and constitutes the hydrologic data referred to as "runoff."

The next term "evapotranspiration" is a water loss from the watershed as transference from liquid to vapor occurs. It consists of (1) evaporation from open water surfaces such as lakes, streams, bare soil, and plant surfaces, and (2) transpiration, which involves the movement of liquid water from the soil through the plant to the leaf surface and its subsequent change from liquid to vapor. Evapotranspiration is an energy process, and is dependent on the sun for its energy source. This is a definite water loss and involves the water being returned to the large scale system.

Surface storage is water retained in ponds, sloughs, lakes, and other means of retention. Change in level occurs due to evaporation and ground water percolation.

Soil Moisture Deficit, SMD, is directly related to evapotranspiration. A porous medium such as soils will retain some water in its interstice, the amount depending largely upon texture and structure. Soils differ in their capacity to hold water, the fine textured soils holding more than the coarse textured. The amount of water held in a particular soil against the force of gravity is referred to as "field capacity." Water infiltrating into the soil must satisfy the "soil moisture deficit," the amount of water below "field capacity," before percolation will proceed downward to the ground water. Ground water is the region where all the interstices are completely filled with water. Movement within this water reservoir is dependent on the geologic formation.

As to the inter-relationship of these terms, from an agricultural standpoint we are very much interested in SMD or "soil moisture deficit." If this is maintained at a minimum and other environmental conditions are equal, plants will respond favorably. Evapotranspiration is entirely responsible for the occurrence of this SMD. The amount of water a soil can store varies from less than ½ inch per foot of soil to over 2½ inches per foot. Direct field measurements can be made of the storage capacity of a soil, or it can be estimated in the laboratory. These measurements are presently being made on many of our Indiana soils. The rate of evapotranspiration is dependent on isolation, wind, vapor pressure deficit and temperature. Naturally the highest rate occurs during the growing season when rainfall is normally the lowest and most irregular. These rates can be estimated by measuring the SMD, however, this is slow and laborious. Attempts have been made to estimate this rate by the use of climatic data. Since temperature is a climatological parameter easily measured, and taken in the routine weather station observations, several attempts have been made to relate this with evapotranspiration. Notable of these are the Blaney-Criddle and Thornthwaite formulas. These give reasonably accurate estimates if adapted to a particular geographic area, and the period of time is extended over several days. Other relatively simple measurements which have been correlated with evapotranspiration are net radiation, and evaporation from the Weather Bureau Class A open pan, the Livingston atmometer, and the Bellani plate. Also, Penman of England has derived a formula combining theoretical and emperical consideration involving all the influences of evaporation. Modifications of this equation have been developed in our country by Van Bavel and others. None of these are extremely accurate on a day to day basis, but approach it over a period of several days. These measurements are especially helpful to a farmer who is equipped to irrigate. Rates as high as 0.36 inches for one day have been measured in Indiana, and for a period of several days average 0.23 inches per day. The rate for July and August ranges from 0.16 to 0.20 inches per day with the overall average about 0.18 inches.

Ground water is the source of water for all our wells. The lowering of the ground water level always creates considerable interest. Naturally pumping will lower the level, and the only source of recharge is from the precipitation over the watershed surface. A relatively small amount of water may flow back into ground water storage during high flow of a river or stream; but this is usually minor. Also a considerable amount of water may enter the ground water storage from streams which have porous beds. Measurements taken the past few years by the U. S. Geological Survey indicate fluctuation in ground water levels in Indiana have been minor, other than in a few regions of heavy withdrawal. In general, there is an abundant supply of accessible water in the glacial Wisconsin drift and outwash plains of Northern and Central Indiana, but only small supplies are available from the Illinoian drift and unglaciated areas of Southern Indiana.

A crucial area in the hydrologic cycle and which does not appear in the equation is at the point of water entry into the soil. The rate of infiltration will largely determine the fate of water in a particular storm. There are four general situations; namely:

1. The rainfall intensity is less than the infiltration rate, and the rainfall amount is less than the soil moisture deficit. This results in no surface runoff, ground water accretion or increase in stream flow.

2. The rainfall intensity is less than the infiltration rate and the total amount of rainfall is greater than the soil moisture deficit. This results in no surface runoff, an increase in ground water accretion and an increase in stream flow.
3. The rainfall intensity is greater than the infiltration rate, and the total amount is less than the soil moisture deficit. This results in surface runoff, no ground water accretion, and some increase in stream flow.
4. The rainfall intensity is greater than the infiltration rate, and the total amount is greater than the soil moisture deficit. This results in surface runoff, ground water accretion and increase of stream flow.

Relating the overall equation specifically to Indiana, and disregarding the L (Leakage), it should be apparent that the three right hand terms are in reality water storage. They will fluctuate, but in the humid area where the hydrologic year is taken as beginning March 1, on this date SMD can be considered as zero, and over a period of years surface storage and ground water will assume a constant level. Runoff and Evapotranspiration remains as water loss terms and it can be assumed:

$$P = R.O. + E_T$$

or

$$P - R.O. = E_T$$

Taking the 25 year records (Table I) for all of the 18 watersheds and applying this revised equation, the annual E_T averages 26.7 inches.

Table I. Rainfall, Runoff, Exapotranspiration relationships for the 18 major watersheds of Indiana. Record taken for 25 year period 1929-1954.

Watershed	Rainfall (Inches)	Runoff (Inches)	Calculated Evapotranspiration (Inches)
Lake Michigan	39.4	10.7	28.7
St. Joseph	36.0	11.5	24.6
Kankakee	38.7	10.9	27.8
Maumee	34.6	10.1	24.5
Tippecanoe	35.9	11.5	24.4
Upper Wabash	37.6	11.1	26.5
Mid-Wabash	38.4	11.2	27.2
Lower Wabash	40.4	11.3	29.1
Upper White, West Fork	38.2	11.7	26.5
Lower White, West Fork	41.4	12.8	28.6
Upper White, East Fork	39.6	13.5	26.1
Muscatatuck	43.9	14.8	29.1
Lower White, East Fork	42.1	14.8	27.3
Patoka	43.0	16.2	26.8
Whitewater	38.5	13.1	25.4
Laughery	41.3	14.1	27.2
Mid-Ohio	42.0	16.8	25.2
Lower Ohio	42.9	17.9	25.0

This amount is very uniform from North to South. The extreme for any of the watersheds on either side of this average is less than 2.5 inches. The standard deviation for all the watersheds is 1.71 inches.

On all the watersheds averaging more than 40 inches rainfall, the average R.O. is 14.8 inches and the E_T is 27.3 inches, while the watersheds averaging less than 40 inches have a R.O. of 11.5 inches and an E_T of 26.2 inches, a difference in E_T of about 1 inch. Six watersheds along the Northern border of the State have an average rainfall of 36.9 inches, a R.O. of 11.0 inches, and an E_T of 25.9 inches, while six southern watersheds average 42.5 inches of rainfall, a R.O. of 15.8 inches and an E_T of 26.8 inches. Therefore, the additional precipitation of Southern Indiana is principally utilized as runoff.

Attempts have been made to suppress evaporation from bare soil by mulches, and other conservation practices (3). Monomolecular layers of long chain alcohols such as hexadecanol have been reported to reduce evaporation by as much as 30% on open water surfaces. There have also been reports of using this substance to reduce the transpiration rate of plants, but this has not been definitely verified. There are many who ascribe to the idea that the future of the agriculture water economy lies in this area, that is reduction of evapotranspiration. It may well be. Certainly research should be continued on the physics involved in the evaporation processes, and the physiology of plants in water use.

From an Agricultural viewpoint, minimizing soil moisture deficit is most important in maximizing producton. We have in Indiana about 1½ millions acres of soil on which moisture is an acute problem almost every year. These areas are principally in the northern sandy regions, along the river bottoms in central Indiana, and on a large section of the Wabash Valley in Southwestern Indiana. The problem then is to find a source of water to supplement these acute areas and thus alleviate the SMD during the periods of low summer rainfall. The means of supplementing this water is commonly known as "irrigation."

Ground water is one source. This is a vast resource, however, no one seems to know just how much. It appears to be ample in some regions, particularly in the northern areas of the state. But this source is not inexhaustible as it ultimately must come from precipitation, and if withdrawal is greater than recharge, eventually there will be a problem.

The other source is runoff. It is obvious that some runoff must be maintained in our streams and rivers as base flow. An estimate of the runoff necessary to maintain this base flow is made by taking information from the Indiana Water Resource Committee report on a typical watershed and using runoff data for the period May through September, about 8.50 inches annually should be a conservative estimate. If this estimate is anywhere near correct, then in Northern Indiana there is approximately 3 inches of water and in Southern Indiana 7 inches which is excess flow and is lost as flood water. These are the peaks of our stream hydrographs. One approach is to transfer these peak or excess Runoff, R.O., to surface storage, S. This does not upset the hydrologic equation, but merely alters the terms, changing R.O. to S. and ultimately to SMD and thus maximizing our agricultural resource.

To be specific, for every 0.6 inch of water taken from the excess runoff from the total area in Indiana, and stored, a million acres could be irrigated to alleviate the Soil Moisture Deficit. This is allowing an acre foot of water for an acre of irrigated land. This would take considerable storage area, for example, it would require 10,000 reservoirs averaging 10 acres in size and 10 feet deep. This sounds fantastic, but this is a natural resource being lost every year.

How much additional output can we expect by management of the SMD. We know from research that a 30 to 100% increase is not unusual. Looking at the production pattern, we note that with supplemental water, the annual yield output should be more nearly uniform each year. Other environmental factors then become the limiting ones. We can also appreciate that the lower the water holding capacity of the soil, the greater the yearly fluctuations. Leveling out these fluctuations gives the producer more stability, and greater flexibility in that he may produce crops which require an ample and an assured water supply.

Some of this may seem far fetched and not economically sound, but in this symposium we are thinking about utilizing our resources for maximum agricultural production. In reality, we are even today working toward these objectives in our conservation and watershed programs.

By way of summarization, I would like to quote Edward A. Ackerman (1) of the Carnegie Institution, who in a talk given at a meeting of the American Association for the Advancement of Science and speaking of the States located east of the 98th meridian where he said: "This is where the major Agricultural development of the future will be, even more heavily weighed than in the past. This region has the lion's share of the land, the water, and the future market. As yet, however, the development of artificially supplied water has been small. Aside from the soil moisture received from precipitation, water is a very minor agricultural input. Perhaps because of this we know very little about its productivity relative to inputs under the conditions prevailing in several parts of the East. Yet when we view such important potential agricultural areas as the lower Mississippi Valley this productive promise of water application appears to be of first rank." He further states: "The first need for action therefore, is rigorous economic evaluation of the relative productivity of water in humid land cultivation, considered in the light of modern agricultural technology. I believe that wise and fruitful public investment cannot be made for water development without the results from such studies."

We may not be ready to build 10,000 reservoirs in Indiana, but its food for thought for food and fiber for the future.

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