The Effect of Deforestation upon the Water Level of Montgomery County.

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HISTORICAL.

The relation of the forest to many problems of vital interest to the welfare and prosperity of the people is becoming more apparent. Until comparatively recent times the far reaching influence of the forest has not been seriously considered, but the gradual disappearance of our vast areas of forest cover and the simultaneous appearance of certain phenomena that are, in the popular mind, probably incorrectly in many cases, ascribed to the cutting off of the forests, has stimulated interest and study along these lines. European countries were the first to recognize the importance of these questions and have consequently taken the lead in matters that have to do with their study or solution. Our own vast forests, with their seemingly inexhaustible supply of timber, have, until recently, blinded us to the facts and lessons which other nations have begun to learn.

One of the far-reaching aspects of forest influence is its relation to the ground water level. Influenced by public men, the press, private prejudices, etc., the public is divided on the question, the partisans of one side asserting that forests have a beneficial effect upon the water level, the others that they do not. Scientists are not agreed upon the subject, and many observations and experiments have been made which give conflicting results. The greatest faults have been that the areas under consideration have been too large for careful study, preventing definite conclusions. Really simple and trustworthy data in sufficiently comprehensive quantity has not been secured. We have deemed it possible that some definite conclusions might be reached by obtaining from a small area all statistics and data available regarding the past and present water level, also the forest, swamp, and drainage conditions. This paper has been undertaken to show the effects of deforestation upon the water level in Montgomery County, Indiana.

Source and Disposition of Water.

Source.—It is deemed advisable to consider first the geological conditions which govern ground water. All terrestrial water is drawn primarily from the ocean, from whence it is taken by evaporation and carried by winds to be deposited upon the surface of the ground, principally as rain but partially as snow, mist, fog, or dew. There can be no other source of ground water available to man in any portion of the globe, with the probable exception of the special cases in which sea water penetrates through the pores of the rocks for a considerable distance inland in coral and other islands of a porous material.

Evaporation.—The rainfall is disposed of in a variety of ways. A great portion of it is returned to the atmosphere in the form of vapor by evaporation. This may be made to include the great amounts given off by vegetation in transpiration. A small portion of water is used in supplying the organic needs of the plants. The proportion that evaporates from the surface of the soil varies greatly under different conditions. Winds, a warm temperature, sunshine, etc., are very conducive to evaporation. The character of the soil and soil covering also has a great influence upon the amount of water returned to the air, a mulch of any character reducing the same.

Run-off.—Another portion of the water which falls upon the earth is known as run-off. This may be divided into two classes: surface run-off and seepage run-off. That portion of the precipitation which flows over the surface of the ground into streams and rivers without gaining access to the soil is known as surface or superficial run-off. By seepage run-off is meant that portion of the rainfall which sinks into the earth but which later reappears on lower levels as springs, seeps, etc., and joins the surface run-off. Another portion of the water is known as deep-seepage, and this sinks into the soil to such depths that it does not later reappear on the drainage basin.

Underground Water.

The amount of water which enters the soil, rocks, and other materials, varies greatly with the nature of the materials, the porous mediums absorbing the most water. The porosity of a soil or rock is determined by the fractional part of it which is occupied by the open spaces.

In Drift.—Drift is a heterogenous mixture of clay, sand, gravel, and boulders left by glaciers. It varies from very porous to impervious, ac

cording to the relative amounts of sand and clay. Water is also found in this in more or less tubular channels a few inches in diameter as well as in the interstices between the particles. Sands and gravels are very porous, the water sinking into beds of such material and the whole mass being saturated with water below the water level. Clay is very impervious to water.

In Rock.—Water found in the pores of rocks is given up readily only in the coarser rocks such as sandstones. The waters found in finer grained rocks are generally from joint, fault, or foliation planes. In limestone the water occurs mainly in channels and caverns which have been dissolved out or eroded by water. The amount of absorbtion also depends upon the inclination of the porous beds, the gently inclined ones absorbing more than the steeper ones.

Water-table.—As the water passes down through the ground it soon reaches a level at which the soil is completely saturated. The surface of this saturated zone is known as the water level or water-table. Above this plane the soil contains a large percentage of moisture which is a most important factor of plant and animal life, but only the water beneath this is generally included in the term underground water. The water-table in general follows the contours of the overlying soil, but the angles and slopes are much less abrupt than the surface of the land. The depth of the water-table below the surface of the ground varies greatly in different localities. In regions of abundant rainfall it is generally within a few feet of the surface, while in arid countries it may be hundreds of feet below. Moreover, the water level of any locality is subject to changes because of seasonal variations of rains and drouth. Underground water, besides being drawn up as soil moisture by capillarity, also creeps laterally, its direction and rapidity of flowing depending upon the porosity of the soil and rock through which it passes.

Forests and Water Level.

Regarding the effects of forests upon water level, it is evident from the above considerations that any factors which tend to increase the conditions that make it possible for a larger per cent. of the precipitated water to enter the soil, will aid in raising the water level of the region on which the rainfall occurs, and any agent which tends to increase evaporation, surface run-off, etc., will help to lower it. Let us now consider the importance of the forest as a factor in both of these conditions.

Rainfall.

The water level of a region is necessarily affected by the amount of precipitation which falls upon its soil. It cannot be said, however, that forests have any great influence upon the rainfall of a country. This question has long been debated but no conclusion, backed by convincing proofs of scientific exactness, has been reached. It is true that rainfall is most abundant where forests grow, but it is more reasonable to believe that rainfall controls the density and distribution of the forests rather than that forests are great factors in determining the amount of rainfall. Precipitation takes place whenever the air is suddenly cooled below the dew point. Forest air is cooler and contains a relatively greater amount of moisture than air in the open, and for this reason it is fair to infer that forests may have at least some effect in increasing local precipitation. The trees also have a mechanical effect in retarding a vapor laden wind, which condition may be conducive to the precipitation of moisture. On the other hand, the following quotation from Blanford (3) shows the opinion that meteorologists are adopting. "As a result of a long study of rainfall in India, and perhaps no country affords greater advantages for the purpose, I have become convinced that dynamic cooling, if not the sole cause of rain, is at all events the only cause of any importance, and that all the other causes so frequently appealed to in popular literature on the subject, such as the intermingling of warm and cold air, contact with cold mountain slopes, etc., are either inoperative or relatively insignificant."

Many experiments and observations made in Europe and elsewhere show an excess of rainfall in forested areas over that of open countries. Some of these excesses were so small, however, that they might have been due to errors in rain gauges and other extraneous conditions which affect them. In Prussia the following records have been gathered from the ordinary meteorological stations showing the excess of rainfall in forest stations over those in the open regions.

Between sea level and 328 feet elevation, 1.25 per cent.

Between 328 and 556 feet elevation, 14.2 per cent.

Between 1,967 and 2,297 feet elevation, 19 per cent.

Between 2,297 and 2,625 feet elevation, 43 per cent.

These figures seem to show that forests have very little effect on rainfall in the plains, but that their influence becomes greater with increasing

elevation. In studies made by Schubert (31) in Silesia a few years ago, the experiments indicated that the rainfall varies with forest cover and altitude as $529 + 0.78$ p. $+ 0.57$ a, that is, precipitation varies above a constant amount by 0.78 mm. for each per cent. of the surface of the country under forest cover and 0.57 mm. for each meter in altitude. It is further stated that beyond about 50 per cent. of the total forest area, forest cover seems to have little additional influence upon rainfall, so that in Silesia, which has about 660 mm. rainfall and 29 per cent. forest cover, complete deforestation would reduce this amount only 5 per cent., and 20 to 80 per cent. additional forest cover would increase it but by 1 per cent. Schubert (32) has also presented data for the provinces of West Prussia and Posen and this data corresponds closely with that compiled in Liberia and Sweden. "Correlating these three series of data it may be stated generally that at altitudes under 500 meters an elevation of 100 meters increases the rainfall by 8–12 per cent.—the higher figure for the drier region—while in a country averaging 15–25 per cent. forest an increase of 10 per cent. in the forested area gives a corresponding increase of 1–2 per cent. in rainfall." Near Nancy, France, observations were made for seven years in two stations, one in a forest and the other in an almost woodless country. The results were as follows:

	Excess in Forest.
February to April	7 per cent.
May to July	13 per cent.
August to October	23 per cent.
November to January	21 per cent.
Mean of year	16 per cent.

This shows an increase of 16 per cent. at the forest station. Even this, however, cannot be taken as entirely conclusive proof because other factors may have helped to produce the difference. Willis L. Moore, Chief of the U. S. Weather Bureau, says: "The records of precipitation of the United States Weather Bureau do not show that there has been any appreciable permanent decrease in the rainfall of any section of the United States." It should be said of the statement of Moore's that this conclusion was given in a paper prepared to prove that the removal of the forest has not influenced the erosion of the surface of the ground or the

water level of the streams. But his report has been shown to be so full of glaring inaccuracies and misstatements that its conclusions are almost wholly discredited by scientific men. (12), (29), and (38.)

Other literature, much of which has contributed nothing new to the subject, has been gone over and after considering all the facts it may be safely said that the weight of evidence seems to show that forests do increase precipitation, at least to a small extent.

Evaporation.

Under the best of conditions much of the precipitated water is lost by evaporation. The proportion evaporated varies greatly in different parts of the world and under different conditions of season and soil. It depends principally on the temperature, the wind, and the amount of moisture already in the air. That the forest retards evaporation cannot be denied. The shade which it affords the soil and its relatively cooler temperature in summer retards evaporation to a great extent. The greater amount of moisture in the atmosphere of the forest is another factor which reduces evaporation. Winds are checked by the forest and their power to take up moisture limited. The wind and sun in winter evaporate a great portion of the snowfall. In the San Bernardino Mountains, snowfalls a foot in depth are frequently evaporated in two or three days without even moistening the soil. The forest aids in reducing this loss in so far that it furnishes shade and checks the wind. Experiments in Germany have proved that evaporation under trees is about one-half of that in the open and show a saving of 21 per cent. of the precipitation by the woods. The evaporation and saving by the forest were both greatest in May and June. It was also found that deciduous trees when in leaf retarded evaporation more than the evergreens and that evaporation under young trees was only 20 per cent. less than in the open. Following is data from a series of investigations by Dr. Ebermayer and by German investigators:

EVAPORATION IN WOODS IN PER CENT. OF EVAPORATION IN THE OPEN.

	Dr. Ebermayer's Results.						German Observations.		
	Water Surface.		Bare Soil.		Soil Under Forest Litter and Within Forest.	Rainfall.	Water Surface.		Rainfall.
	Open.	Woods.	Open.	Woods.			Open.	Woods.	
April	1	.45	1.15	.64	.27	1.75	1	.51	1.37
May	1	.43	.91	.37	.16	.68	1	.47	1.35
June	1	.36	1.07	.38	.14	1.46	1	.41	1.91
July	1	.35	.89	.34	.12	1.02	1	.38	2.33
August	1	.34	.87	.36	.11	1.00	1	.36	1.98
September	1	.33	.92	.39	.11	.59	1	.35	2.54
October	1	.41	1.26	.44	.18	3.45	1	.37	8.49
May-September	1	.36	.93	.35	.13	.95	1	.39	2.02

The difference in instruments used by Dr. Ebermayer or their exposure is probably the cause of the relatively slight differences in the results. One of the most striking features of the table is the retarding effect that forest litter is seen to have upon the soil beneath. About seven-eighths of the loss of water by evaporation is cut off by the forest and litter. The stations of Prussia allow the following average for evaporation, the amount evaporated in the open field being called 100:

	Evaporated.	Retained More Than in Open Fallow Field.
	Per Cent.	
Under beech growth	40.4	59.6
Under spruce growth	45.3	54.7
Under pine growth	41.8	58.2
From cultivated field	90.3	9.7

Other data from Prussia are also given which show that greater amounts are lost by exaporation in the open than in the forest. Investigations by Shimek (34) in western and northwestern Iowa show that evaporation is much greater on prairie surfaces than in adjacent forests. It must therefore be admitted that wastefulness by evaporation from the ground is reduced by forest cover.

Transpiration.

Great amounts of water are returned to the air through evaporation from leaves and stems of plants. This is known as transpiration. Careful experiments and estimates have shown that plants differ widely as to the amounts transpired and that conditions such as wind, the amount of humidity, sunlight, etc., affect this to a great extent. An oak tree, with seven hundred thousand leaves, will transpire one hundred and eighty gallons of water per day. Von Höhnel estimates that a beech will transpire about two thousand two hundred and fifty gallons of water in one summer. Schleider believed that a forest transpired three times as much water as would be evaporated from a water surface equal in extent to the territory covered by the forest. Schübler considered it only one-fourth as much, and Pfeff, who studied only one oak, found it to vary from 0.87 to 1.50. Hartig believed the transpiration from a forest less than the evaporation from bare soil of equal extent. Schübler found that a forest transpired .06 as much as evaporated from bare soil and from sod three to five times as much. Investigations by Wollny show that agricultural crops and forms of low vegetation, such as weeds, transpire greater amounts than do forests. Risler, after a long series of experiments, concludes that forests take up less than one-half as much water from the soil as the average agricultural crop. Some investigators claim that the ground water level of a forest is lower than that in the open, and that this is caused by excessive transpiration. Others draw opposite conclusions. On the whole, however, it may be said that the forest, at least, transpires no more water than does any other ordinary form of vegetation.

Forests and Run-off.

It is generally believed that forests are great regulators of run-off, that is, that they increase seepage run-off and decrease surface run-off. This is true to such an extent that the government has recently made provision for buying certain timber lands with the express purpose of protecting the headwaters of several navigable streams.

Many factors enter into the question such as the slope of the ground, the underlying rock, the amount and length of time of precipitation, etc. The forest canopy intercepts the raindrops and extends the period of time during which the rain reaches the ground. This gives the soil more time in which to absorb the precipitation and thus lessens the surface

run-off. An added advantage is also obtained in that the force of the raindrops is diminished and prevents the soil from becoming hard and compact, thus reducing its absorbtive power. It must not be forgotten, however, that the branches of the trees catch from 8–10 per cent. of the rainfall, and this is, of course, immediately evaporated.

The character of the soil has much to do with the distribution of the fallen water. Many experiments have been made concerning the conductivity of certain soils, but as many of these have led to contradictory results, no attempt will here be made to discuss them. It is fair to say, however, that the forest soil is well adapted to absorb a great deal of water. The humus and litter of leaves, limbs, etc., serve to keep the soil in a loose, spongy condition, which undoubtedly assures a great absorbing capacity. The great mass of roots also aids in this and facilitates the passage of the water down through the soil. It may be true, however, that after a long continued rain the forest soil will become so saturated that the water will run off as freely as from bare soil. The forest floor offers many obstructions and obstacles to the water that is not immediately absorbed as it runs over the surface of the ground. These retard its passage and thus more is taken into the soil.

In the case of bare land, the water is gathered into little rivulets which form larger and larger ones, which flow with constantly increasing velocity with the result that very little water gets into the soil.

Forests also have a great power in conserving snow water. Mattoon (21) in Northern Arizona has shown that the forest retains the snow later in the spring than does the open parks. The snow melts more slowly and more is taken into the earth. A layer of ice which kept the water from entering the soil was formed above the soil and under the snow in the park, while this was absent in the forest.

By retaining the rainfall the forest is a benefit in two ways. It tends to prevent disastrous and destructive floods, and holds the water until long after precipitation and gives it out slowly to streams, springs, etc., in times of drouth. Many, however, do not concede the regulating effect of the forest and much discussion has arisen concerning the subject. Professor Engler reports that at the Swiss Station experiments made for three years show that the springs in times of drouth continued to give out water for a longer period in a forested region than in an unforested one. Buffault (4) discusses the evidence reported at the Navigation

Congress at Milan in which Wolfschütz of Brünn gave proof to show that the efficacy of the forest in retarding water fails in times of long-continued and extraordinary rain, and Honsell claims that the best wooded basins of the Black Forest, Harz, Spessart, etc., contributed most of the water of the floods of the Rhine in 1882. Like experiences were reported from the watersheds of the Elbe in 1897, of the rivers Enns, Traun and Ybbs in 1899, and from the densely forested Riesenwald in Silesia in 1888, 1897 and 1903. Wolfschütz, however, thinks that forests have a limited and local influence in certain regions in reducing floods. Lauda, director of the Austrian Hydrographic Bureau, comes to the conclusion that weather conditions preceding the precipitation has a bearing on forest influences, the forest having the greater retentive capacity after a drouth. Ponti, an Italian engineer, asserts experiences of increased floods due to deforestation in Sardinia, Sicily, and Campobasso, and of the watersheds of Adda and Matero. He also finds favorable influences from forest planting in several provinces. The Russian, Lokhtine, cites a long series of general experiences and observations from parts of Europe and especially from Russia which indicate injurious effects from deforestation. Other instances were given which show that the water level is decreasing with deforestation.

After considering these and much additional testimony on the subject, one is justified in saying that forests do act as great regulators of rainfall but that their value in this respect is a relative one which is modified by many conditions.

Forests and Water Level.

Let us now consider the relation of forests and water level as shown by observations and experiments.

Professor Bühler [see (7)] found a much lower ground water level under forest growth than in the meadows. Ototsky in the steppes of Russia, where a low rainfall prevails, came to the same conclusion as Bühler. Ebermayer and Hartman in Bavaria, however, found no difference between the ground water level of forest and field. Otoski states that Wollny and King found the ground water level lowered by a forest and that this caused its lowering in adjacent open soil. In a bulletin by A. Tolsky and E. Henry (40) it is shown that observations made independently in France, near Nancy, and those made in the Russian Steppes

in 1895 and in the neighborhood of St. Petersburg in 1897 and later, all agree in the following, at least as far as Europe is concerned.

(a) Water level is never higher under a forest cover than under bare soil. (b) The surface of ground water is always found farther from the surface of the ground under a forest than outside of it, this being true for both summer and winter. (c) Fluctuations in ground water are smaller in forests than outside of them. (d) Water level is lower in old forests. (e) Depressions of water level is greater in dry climates.

Wysotski, a Russian, finds that forests lower ground water level and also streams in summer time, but that this effect is reduced in mountainous regions. Buffault (4) in a paper gives the work of others. The Russian, Lakhtine, gives the statement of Schreiner and Copeland regarding conditions in Monroe County, Wisconsin, where in seventy years the forest area was reduced from 83 per cent. to 69 per cent., and the effect was noticeable in 1887 in a striking manner by low river beds and abandonment of mills. Results of a special commission on the Dnieper and its tributaries show the deforested basin as retaining from 3–20 per cent. less water than the forested basins, in proportion to the deforestation. In the Soma, a gradual decrease of the average water level has been observed from 1888 in proportion to progressive deforestation. Similarly on the upper Bielaja at Oufa, where deforestation has been going on from 1887–1900, the average water level has decreased, while on the lower Bielaja at Grouzdecka, where the forest cover has remained undisturbed, the water level has remained practically the same. Like observations are cited for the Volga basin. Experiences were also given by the department of Aude in 1893. The main river rose fifteen feet. In the two branches which passed through a country mostly deforested, great damage was done. In another branch which ran through a well forested region, little damage resulted. From these evidences, it is seen that although the water level under a forest may be lower than in the surrounding land, it is evident that deforestation causes a lowering of the ground water which is very detrimental to the continued flow of springs, streams and wells.

MONTGOMERY COUNTY.

We have discussed the general relationship which exists between forests and water level. We shall now take up our own particular problem and consider the effect which deforestation has had in this county.

Montgomery County is located in the middle western part of the State and contains 504 square miles, or 322,560 acres. The surface is somewhat diversified. The western and central part near the principal streams is hilly and broken; in the north central it is gently undulating, and at the east and southeast flat and level. The northern part of the county is, in general, a prairie region, level or gently rolling. The dip of the underlying rocks gives direction to the drainage, which is generally a little west of southwest. The main stream is Rock River or Sugar Creek, which enters south of the northeast corner and traversing the central area, passes out six miles north of the west corner of the county. Its tributaries from the north are Black and Lye creeks; from the south, Offield, Walnut and Indian creeks. The southern and southeastern parts are drained by Big and Little Raccoon creeks and at the southwest by Coal Creek, which flows directly into Rock River. Glaciers have left the bed rock of the county covered with a drift which reaches in some places to a depth of 200 feet. In only a few places, mainly along streams, does the bed rock outcrop. The average depth of the drift, however, is very much less than the figure given above.

Collection of Data.

In order to discuss this question intelligently, it is evident that one must be familiar with not only the past and present history of the water level of the county, but also the past and present forest, swamp and drainage conditions. To obtain data, trips were made personally to the principal towns in the county. Old residents were interviewed as to the past condition, and well-drillers and diggers were asked concerning their observations as to the water level. Stress was laid particularly on the history of old dug wells, because in these any fluctuations of the water level of the region would be evident. Owners of old wells were asked concerning the water level. From men well acquainted in the different communities visited, were obtained names of farmers who had or who would be most liable to have old dug wells on their farms. Letters of explanation and lists of questions were then sent to these men. These questions covered points concerning water level as exhibited by wells, and forest and drainage conditions, both past and present. They were asked to return answers on blanks furnished. One hundred and thirty-six letters were sent out and forty-two answers were received, eight of which contributed nothing to the solution of the problem.

Past and Present Conditions in the County.

Forests.—Early settlers in the county found a vast forest; broken only here and there by paths left by cyclones, and by marshy prairies. Their way had to be cut with the axe, and, from the first, war was made on the tree as an enemy to progress and civilization. Clearings were made and regular logging bees were held where thousands and thousands of trees were cut, rolled together, and burned. Great amounts of timber were used for cabins, fences, corduroy roads, etc. Practically the entire county was covered with this virgin stand of timber. The northern part of the county in the neighborhood of New Richmond, Linden, and Kirkpatrick borders on a prairie country which extends northward up into Tippecanoe, but even there the forests were in evidence. The soil over the greater portion of the county was covered with leaves, underbrush and general litter, under which was a thick layer of humus which acted as a reservoir for the rainfall of the region.

The needs of a growing population and civilization has increased the drain upon our once luxuriant forests until, today, little remains to remind us of them. Only here and there are patches of woodland, and these are so thin that they cannot be called forests at all. Fields, pastures and barren slopes have taken the place of our great stands of timber, and this has done much to lessen the efficacy of the soil as a retainer of rainfall. The following figures from the report of the statistician show the above conditions in the county:

1881	67,574 acres of timberland
1882	62,983 acres of timberland
1883	69,390 acres of timberland
1884	69,451 acres of timberland
1885	46,508 acres of timberland
1886	44,183 acres of timberland
1900	7,184 acres of timberland

Inaccurate data is responsible for the discrepancies in the early returns; the later reports are more reliable.

Streams.—It is evident to any one who has given the matter the slightest consideration that the flow of streams in the county is much changed. The amount of water carried by the streams is probably no less, but the flow is much more irregular, being greater than formerly in times of rain and lower in times of drouth. This is very noticeable in

Sugar Creek. This stream was once much used as a means of transportation. In 1824 William Nicholson came from Maysville, Kentucky, to Crawfordsville in a keelboat of ten tons burden, which landed at the mouth of Whitlock's Spring Branch. Trips were also made between Crawfordsville and Terre Haute in flatboats. Only the lightest of canoes can now do so. Records also show that Sugar Creek has furnished the motive power for at least nineteen mills situated along its course in Montgomery County. Not over three of these mills are now in operation, and these have to depend upon steam during most of the summer months. It may be that other factors, such as competition, have helped to cause their abandonment.

No accurate information regarding the maximum and minimum flow of the stream in different seasons in past years can be obtained, but it is the prevailing opinion that floods are now higher and more frequent and that the waters are lower during the summer months than formerly. The smaller streams of the county have also been affected. One stream near New Market has been reported as being dry for half the year, whereas, formerly it was never dry. A stream near Waveland under my own observation used to furnish fishing and swimming pools for the boys during the summer, but such sports are now rarely possible in this stream. Numerous other examples of the same nature can be cited.

This evidence proves that the water escapes from the ground in times of rain faster than formerly. From this it is evident that less water is held in the soil, thus causing a corresponding decrease in the water level of the county.

Springs.—The early settlers built their cabins where fresh water was easily obtainable. Springs were found on almost any hillside and wells were not thought of. Many springs in all parts of the county have either dried up or their water flow has been reduced. Several large springs just southwest of Crawfordsville have disappeared. Many springs have been reported as having failed or decreased in water flow in the neighborhoods of Ladoga, New Market, Waynetown, Darlington and elsewhere, all of which show a falling of the water level.

Wells.—The letters sent out dealt with the water level of old dug wells and the forest and drainage conditions in their vicinity. The data received was not such that it furnished a very reliable basis for positive conclusions and was only useful in connection with other information secured in a variety of ways. In some cases it must be remembered that

geological and geographical conditions would maintain the water level in certain small areas irrespective of the changes in soil cover, however important these might become. Many cases were cited by residents of wells which have failed. Many old wells have been dug deeper in order to keep up the flow of water. In many localities well diggers reported as having to go deeper for water than they formerly did. The weight of evidence shows that the falling of the water level is general in the wells all over the county.

Swamps.—Many places in the county have been wet and swampy. Natural ponds of greater or less extent were numerous, some of these being ten acres in area. The water level was very near the surface in these places. The region around Whitesville was especially very wet, water even running into shallow post holes. Such places have now all been drained and the ground water level much lowered.

Drainage.—A great amount of drainage has been done in the county. The county surveyor reports about 200 county ditches, open and large tile, with a probable average of two miles in length, which makes a total of 400 miles. The county is also well underdrained by many thousand rods of private tile ditches under farm lands. Swamps, ponds, wet fields, etc., have been drained and much of the water that sinks into the soil is quickly carried by ditches to the nearest stream.

Water-level.—That the water level of the county his lowered certainly needs no additional proof. Observant and intelligent men in all parts of it have given their opinion that this is undoubtedly so. The lowering has been greater in some places than in others. As reported by wells, the lowering has been 2–9 feet.

Causes of the Change.

Deforestation.—That deforestation has been a great factor in causing a lowering of the water level can not be doubted. The cutting off of the timber has increased evaporation and surface run-off to such an extent as to affect the water table. One man gives the following experience: A well was dug on the farm and in ten years it went dry. During that time, a large tract of timber was removed from the farm. Another well was then dug with the same result in a few years, deforestation also having proceeded during the time. The same occurrence also happened again. Of course, it can not be asserted that deforestation was the sole cause of the lowering.

Drainage.—Drainage is also responsible in a great measure for the lower water level. The miles of tile and open ditches, city storm sewers, etc., carry a great part of the water to the streams as soon as it falls. The water is thus carried away instead of being held to feed the wells, springs, etc. Two instances have been given me in which wells went dry after sloughs, lower than but near the well, had been drained.

Greater Amounts Used.—A growing population has increased the drain upon the underground water supply. Water is put to more uses than formerly and this, no doubt, has its effect upon the water level.

RELATIVE IMPORTANCE OF ABOVE FACTORS.

It was hoped that it would be possible to separate the effects of deforestation and drainage and determine just the part each had played, but this can not be done in Montgomery County. My own judgment, based on field work and reported data, is that drainage has played as great a part in the lowering of the water level as has deforestation.

The results of this study are not as definite as were at first expected, but it is believed that the rather thorough study of such a typical county in Indiana is well worth recording, and it is hoped that it may induce others to undertake similar surveys in various parts of the State until more definite data are discovered upon which to base conclusions that, as far as Indiana is concerned, will be sufficiently reliable for real scientific work on the problem which depends upon these things.

This investigation was carried on in the Botanical Laboratory of Wabash College under the direction of Prof. M. B. Thomas.

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