actually occurred, the lake would have had sufficient capacity to store it all without great overflow.

There have been no storms within the period of record of anything like twice the depth of that of June, 1912. In fact only one storm within the record was greater—viz, that of October, 1910. The October storm was only 1.65 inches deeper than that of June, 1912. While we have no record of the behavior of the lake at that time, the local testimony merely indicating that it overflowed broadly, no argument is needed to establish the assurance that under the conditions of lake regulation recommended in this report, the lake basin would have stored all the run-off water and have had ample capacity to spare.

From the foregoing it appears that a provisional plan for lake maintenance recommends itself as follows: Let the minimum lake level be established at 16 feet above tide; let the maximum working level be elevation 19; let the lake capacity between 19 and the point of overflow—say 21.5—be held for emergency storm storage. If it should ever happen that with the lake at elevation 19 a storm equivalent to that of June, 1912, occurs there will yet be sufficient capacity up to the point of overflow to store nearly all of the run-off water. It seems well-nigh impossible, however, that such a storm ever will occur when the lake is at elevation 19. The rainfall records show that two great storms have never occurred in one year, and inasmuch as it will require a great storm to raise the elevation to 19 in the first instance, a second one of like intensity is hardly to be expected. Therefore it will be entirely safe to use the St. Lucie outlet canal to the extent of the normal daily requirements for water power and navigation and the other drainage canals for the incidental irrigation and navigation up to the time that the lake rises to elevation 19. Then the St. Lucie outlet should be opened to full capacity and maintained thereat until the storm season has passed. If the capacity of that proves to be insufficient to prevent the lake from rising too rapidly above that elevation the locks of the great drainage canals leading from the lake can be opened. This schedule promises entire safety and at present writing appears fully practicable. Subsequent experience will probably indicate another scheme of control, but the change can hardly be sufficiently radical to affect the broad conclusions here stated.

Records of rainfall since 1899 indicate a distribution of storms that will make it possible to arrange in advance a schedule of lake operation that will rarely if ever be violated. In the 14 years from 1899 to 1912, inclusive, the high monthly rainfalls have been distributed over the year as indicated below:

Month.	Monthly rainfall in excess of—			
	10 inches.	9 inches.	8 inches.	7 inches.
January	0	0	0	0
February	0	0	0	1
March	0	0	0	0
April	0	0	0	0
May	0	0	0	2
June	2	3	6	8
July	0	1	2	3
August	3	4	8	8
September	2	4	5	6
October	2	2	2	6
November	0	0	0	0
December	0	0	1	1

It will be seen from the foregoing that all the extremely heavy monthly rates of rainfall above 8 inches have, with one exception, occurred between May 1 and October 31 of each year, while monthly rain in excess of 7 inches has occurred in only four cases outside of this period. This is, therefore, the season of water storage during which it may be expected that the heavy lake-filling rains may come. The lake should always be drawn down to approximately its minimum level (16) in May. On or about June 1 it will be advisable to commence to save all the water possible and continue up to the time that the lake level reaches elevation 19. Probably during the majority of years the lake will not reach that point. After November 1 there is only a remote possibility that heavy storms will occur.

The St. Lucie outlet canal has been planned to a capacity of 5,000 cubic feet per second at elevation 16, and 7,000 cubic feet per second at elevation 19. At the latter elevation the present 3-Mile, Miami, and North New River Canals have a discharge capacity of 1,350 cubic feet per second. The 9-Mile Canal carries no perceptible amount of water from the lake at any elevation up to 20. The Hillsborough Canal and the proposed Palm Beach Canal are at present somewhat indefinite as to capacity. The Miami Canal will probably discharge twice as much water as it now carries after its rock section has been excavated to grade. It is safe to assume that the five canals above mentioned will, at elevation 19, carry approximately 2,600 cubic feet per second which, with the St. Lucie outlet, will give an aggregate capacity of 9,200 cubic feet per second. The capacities at elevation 16 will probably not exceed 6,000 cubic feet per second. The aggregate capacity at the higher level is equivalent to a depth of a little more than 0.04 foot per day on the lake surface, while at the lower level the draft will be 0.025 foot. Thus the average draft through the range of stage from 19 down to 16 feet above tide would be 566,000,000 cubic feet per day, and if no water flowed into the lake a period of 90 days would be required to reduce the level if all outlets were wide open. Of course no such record could be made because of the inflow into the lake. If 5,000 cubic feet per second were drawn through the St. Lucie inlet for power purposes and the other outlets from the lake closed except for incidental water uses, the storage provided between elevations 16 and 19 would suffice for about 139 days without consideration of added inflow supply.

It will be apparent that with the progress of the drainage work, which will include the deepening of the Miami Canal and the completion of the Hillsborough and Palm Beach Canals and the St. Lucie outlet, the outlet capacity from the lake will gradually increase so that the actual lowering of the lake can commence long before the total outlet capacity is achieved. While this is going on the rainstorms of the country will contribute the usual amount of water, the effect of which will be to maintain lake levels. Under these conditions it may be that, unless an unusually long dry season occurs, a year or more after the St. Lucie outlet is completed may elapse before the lake level is reduced to elevation 16. This gradual net reduction of the lake level during and after canal excavation, distributed over a period of four or five years, will not be without its peculiar advantages. A radical change of this kind in the natural conditions of a great area if quickly made is likely to cause many unforeseen contingencies. One of these which is apparent and important is the changed regimen of Kissimmee River. Such a change, if abruptly

made, would cause heavy erosion of the river bed and banks and thereby an unknown but surely enormous quantity of débris would be discharged into the lake, impeding navigation and reducing in some degree its storage capacity. It would also cause local changes in river channel that might not be desirable. The orderly course of nature in making these great physiographic changes is extremely slow and it is well for man to copy nature's program as closely as possible.

SHRINKAGE OF MUCK.

Everglades muck in its present normal condition contains a large percentage of water. Numerous experiments and observations have been made to determine this percentage because the shrinkage that the muck will undergo by reason of the reduction of water content after drainage has very practical significance in determining upon the depth and general regimen of the canals and ditches. The most extensive series of experiments was that conducted by H. A. Kipp and F. F. Shafer in 1910 under the direction of the Office of Experiment Stations, United States Department of Agriculture. The results indicate a water content by volume of 60 to 90 per cent in the virgin muck at a depth below the surface of from 0 to 15 inches, and the approximate optimum water content for agriculture appeared to vary from about 48 per cent at the surface to 87 per cent at a depth of 35 inches. The purpose of the experiments was largely agricultural and the average shrinkage under drained conditions can only be inferred. Entire desiccation would reduce the depth of the muck to a very small fraction of its present depth, but it is obvious that no such condition would be considered in connection with agricultural operations. The reasonable assumption is that the average depth to water table should not exceed 4 feet, although it is admitted that at least one competent authority advocates greater depth. The final word on the subject can not now be given, but whether the ruling depth be 2 feet or 6 feet, it is obvious that the soil at the surface should probably contain from 40 to 50 per cent of water and the proportion should increase with the depth to the point of saturation. In other words, the total shrinkage will vary from about 50 per cent at the surface to 0 at or a few inches above the water table. It is impossible to determine precisely the mean shrinkage, but it is evident that it will not be as great as has occasionally been believed. The commission has made what it believes to be a reasonable assumption in the premises, and if it should prove that this assumption involves a comparatively wide error the difference in actual surface elevations will be inconsequential.

At the beginning of the commission's investigations boxes having a capacity of 1 cubic foot were filled with water-saturated muck, care being taken to avoid compacting the soil to a greater degree than that which existed before the soil was transferred to the boxes. These boxes were then placed in a dry location, sheltered from the direct rays of the sun, but exposed on all sides to the air. As the muck dried out the boxes were pried apart at the joints, so that the air could freely circulate between the sides and the surfaces of the muck block. At the end of about four months the muck was comparatively dry, though by no means desiccated. The shrinkage was uniform in all directions and the cubical dimensions were 8.5

inches. The reduction in volume was therefore about 65 per cent. The commission believes that a reasonable shrinkage factor will be approximated by assuming that the ultimate reduction in depth from surface to ruling water table under the partially saturated conditions that will prevail in practice will be the same as that above indicated for total drainage in the upper foot. Therefore the final plans herein presented are based on the assumption that the upper foot of muck will shrink vertically 7.8 inches, while the remainder of the column down to the water table will shrink not at all. Under this assumption the average condition will be fairly represented. It appears certain from general considerations based upon the commission's observations that the ultimate shrinkage will be no greater than that above indicated.

PERMANENCE OF WATERWAYS.

One of the prime factors in the successful operation of any drainage district is the permanence of the outlet canals. Any well-adjusted drainage system has its canals originally planned to a capacity sufficient to pass the ruling flood. Any substantial reduction during subsequent years means that the drainage system must become inadequate and agricultural development and operation must suffer accordingly. Loss of canal capacity may be the result of many causes, the most important of which are sloughing of canal banks, silting of channel, and the growth of weeds. In the Everglades where the muck banks of any canal must be relatively unstable, where erosion is easily accomplished, and where the semi-tropical water-weed growth is luxuriant, these items are of serious import. Therefore, the commission strongly recommends that all of these contingencies be prepared for at the outset. Prevention is better than cure. Laws and regulations governing the administration of this drainage district should contain strict provisions for canal maintenance. Each farmer should be required, under an inspection and penalty system, to properly maintain the lateral ditches which cross or adjoin his lands. For the maintenance of the larger canals the tax levy should include an item sufficiently large to provide for maintenance under drainage district control and supervision. When the entire district has been drained, a number of suitable dredges in constant operation will be required. Unless such provisions are made the district must within a few years revert to the swamp conditions which now prevail.

For the purpose of determining whether or not any of the main canals already constructed have lost any of their capacity, the acting drainage engineer of the State, at the request of the commission, caused to be made certain cross-section soundings at points at which such soundings had been made during excavations and at the close thereof. These canals have been practically "bank full" ever since they were opened. Consequently the water velocities have approached the maximum. Under ordinary conditions one might expect to find that the canals had been maintained to full capacity or even that they had in places enlarged themselves. Many of the sections were found to be as great as or greater than at the close of the excavation operations. Some of them, however, especially along the South New River Canal, showed marked silting and shal-

lowing. If such results can occur under "bank full" conditions when scouring action must be at its maximum, a more pronounced loss of capacity may be expected in the future when under properly drained conditions in the Everglades the water in these canals will be lower than at present and the velocity reduced thereby.

VALUES OF "N."

In connection with the foregoing discussion it is proper to consider values of "*n*." This letter is a symbol used in the standard channel formula (the Kutter formula) to represent roughness of the sides and bottom of a canal. It is obvious that the rougher the sides and bottom the greater resistance to the passage of water and the slower the velocity of the water. The value of "*n*" therefore increases or decreases according as these surfaces are more or less rough, respectively. As the factor is an important one in connection with the practical planning of canal capacities in the Everglades, advantage has been taken of the canals already existent there to determine by experimentation the values of "*n*" under various conditions.

Values of "n" (Kutter formula) in the Miami, South New River, and North New River Canals.

Location.	Material.	Slope.	Area.	Velocity.	"R."	"n."
Barkleys	Muck	0.0000909	370.7	1.104	4.73	0.0378
Do	do	.0000946	358.5	1.11	4.63	.0377
Zona	Sand	.0000525	373.6	1.13	4.82	.0286
Do	do	.0000454	370.0	1.02	4.76	.0292
Everglades	Rock	.0000568	552.0	1.04	6.34	.0365
Do	do	.0000564	550.0	1.00	6.32	.0422
Do	do	.0000644	547.0	1.01	6.32	.0449

The engineer will readily recognize that the values of "*n*" expressed in the foregoing statement are, for the muck and rock conditions, unusually large. The commission has never seen the results of any observations in which the values of "*n*" are as great as those above set forth, yet these observations were made with the utmost care at three of the regularly-maintained current meter sections. The velocities determined conformed to those repeatedly observed at these stations. The slopes were determined by carefully checked level lines 1 mile long, which lines were bisected by the measurement station locations. Soundings were made along five cross sections, the middle one being the regular station cross section, and the others being made 100 and 200 feet above and below, respectively. Clearly the high values of "*n*" must be caused by marked lack of uniformity in the canal sides and bottom. Better excavation work would undoubtedly correct this condition, and the commission recommends that future canal work in the district be attended by more faithful inspection and a closer observation of neat grade lines than was obviously enforced in the work of the past. The commission believes, however, that under the difficult conditions in the Everglades it will be impossible in practice to achieve a lower value for "*n*" than 0.035. This value has therefore been used in planning all of the Everglades canals with the exception of the Okeechobee-St. Lucie Canal. This outlet will be excavated mainly in stable materials and

there is no reason why under proper supervision and execution the value of "*n*" for this outlet should be greater than that conventionally assumed. Therefore the factor 0.027 has been used in the St. Lucie outlet.

METHODS OF EXCAVATING.

We have nothing original in the way of excavating machinery to recommend. We know of no excavator for muck, sand, and the lighter soils which will give more economical results than the hydraulic dredge.

For excavating rock under water the dipper dredge maintains its supremacy over any other device of which we have knowledge. The rock should be blasted in advance of the dredge, and a well designed and equipped drill scow is the best machine to use for drilling the rock to receive the explosives for this blasting.

Where—as will be the case in the prosecution of the work now under consideration—the volume of work justifies the investment, by the owner or agent, in the necessary mechanical equipment and other competent employees, the owner can prosecute a work of this magnitude at a less cost than the work is likely to be done by contract.

As soon as this work is staked out a dipper dredge with boom of sufficient length should be set to work to build a levee along the outer edge of each berm to hold back the material excavated from the channel by hydraulic dredge and prevent its flowing back into the channel.

Water power.—The construction of the channel which we advocate from Lake Okeechobee to St. Lucie introduces an element of value which does not enter into any other possible canal leading out of Lake Okeechobee. This channel, if constructed as we advise with a grade of two-tenths of a foot to the mile, will use up only 4.9 feet of 15.7 feet, the ascertained difference in level between the lowest permissible stage of the lake (16) and the ordinary stage of the St. Lucie River (0.3). We have designed this channel for a minimum flow of 5,000 cubic feet per second and that volume of water falling 10.8 feet will yield on an efficiency of 80 per cent 4,907 net electrical horsepower. This will be the minimum output, and it will be augmented by every inch of rise in the lake between the limits of control 16 to 19, and at the high stage will reach a maximum output of 6,270 horsepower. The cost of hydroelectric equipment and power house erected will approximate $210,000. The creation of a power such as this was not anticipated when the contract of April 30 was entered into, and hence no provisions was made therein for the preparation of plans and no exact estimate can be made until the plans in detail are prepared, but the estimate given herein is believed to be a reasonably close approximation. The value of this development (located in land remote from mineral fuel supply, and in which wood fuel is limited in amount and subject to consumption more rapid than the recreating powers of nature can make good) is self-evident, and it occurs in a locality from which it can radiate by suitable transmission lines to supply the ever growing need for power and light. One of the power needs to which it can be most fittingly supplied is that for operating pumps during the seasons when the reclaimed Everglades shall need irrigation.

The question of a constant supply of water for operating this power is a most momentous one.

The dry season over which our investigations have extended has been most unfortunate in its limitation of our hydrometric information to previous records to which we can not attach the value of proprietary knowledge, but in its bearing upon the water power problem it has given us a knowledge of very great value in reaching our conclusions. During the dry period, extending over the months of May to September, the discharge from Lake Okeechobee has never fallen below 1,350 cubic feet per second, and the mean discharge has been 2,115 cubic feet per second.

(NOTE.—The actual observations covered only four and one-half months).

We propose to divert the entire flow of Lake Okeechobee into the St. Lucie River through a canal at the easterly end of which we recommend the location of the before considered hydroelectric power plant. From this flow, of course, must be deducted the small volume needed for lockage and sometimes for irrigation.

Although the past season has not afforded us the demonstration of flood and run-off due to rainfall, which we had made rather elaborate preparations to observe and record, we are not left without a basis for determining with reasonable certainty the volume of flood waters that will be stored in Lake Okeechobee and the extent to which these stored waters can be drawn upon to develop water power.

Under the head "Lake Okeechobee run-off" and "Control of Lake Okeechobee," the data secured is discussed and the logical deductions from that data are stated. Note the references to the diagram entitled "Lake Okeechobee storage diagram, June 1–December 31, 1912."

We recommend the development of this water power as a proper conservation of a natural resource of great value now and likely to enhance in value as the years go by.

The channel considered in this discussion will carry 5,000 cubic feet of water with Lake Okeechobee at its low stage and that capacity increases as the lake rises until it has a capacity with the lake at 19 of 7,072 cubic feet per second. The discharge, however, is absolutely under control at the St. Lucie end of the canal.

It is proper to call attention to the fact that the approximate estimate of the cost of the proposed water power ($210,000) hereinbefore given, does not represent the entire cost; for to make this power possible the gradient used is two-tenths of a foot per mile, whereas a channel of smaller cross section would carry the same volume of flow, by reason of greater velocity, on a slope of five-tenths foot per mile, the difference in excavation, stated roundly, is 2,000,000 cubic yards, costing probably $200,000. This cost is a proper charge against the water power, and if it be added to the previous estimate the total cost would be $410,000 for an approximate minimum of 5,000 net electrical horsepower, or, say, $82 per horsepower, which is below the average cost of water powers in the Eastern and Middle States.

NAVIGATION.

As soon as the canals leading from Lake Okeechobee to tidewater were opened their use by motor boat and small water craft commenced and boats of moderate size can now ply between the Atlantic coast and the Gulf of Mexico via these canals, Lake Okeechobee, and the

Caloosahatchee River. Likewise there is now a water route from Lake Tohopekaliga to the Atlantic seaboard through the Kissimmee River, the lakes through which it flows—Lake Okeechobee and these new canals.

The proposed canal from Lake Okeechobee to the St. Lucie River will afford a channel of much greater commercial value than can ever be attained by the lesser channels of the drainage system. This channel will have a depth of 12 feet and a bottom width of 200 feet. At a distance of 24 miles from Lake Okeechobee it will discharge into the St. Lucie River, where it is proposed to construct a lock with a usable width of 30 feet and usable length of 130 feet. The St. Lucie inlet, by reason of its natural advantages, has been reported upon by the United States Engineers (see House Doc. No. 675, 62d Cong., 2d sess.), as deserving of development as a commercial port and harbor of refuge and Congress has accepted a project for its improvement and made initial appropriations for a development, estimated to cost $1,400,000. The opening of the channel which we recommended is looked upon most favorably by J. R. Slattery, major, Corps of Engineers, in charge of United States waterways in Florida. It is our belief that when this channel is determined upon and completion assured, Congress will recognize this construction as a link in a practicable waterway across Florida, provided without cost to the Government, and will proceed to improve the channel from Lake Okeechobee to the Gulf via the Caloosahatchee River, with depth equal to that which will obtain in the Okeechobee-St. Lucie Canal; thus providing an aid for marine commerce the need for which has been felt for generations past.

There should be a proper regulation of the speed of boats through these canals to safeguard the canal banks which under the speeds now permitted in the existing canals are being badly eroded by the swell from the passing boats. Five miles per hour in the smaller canals and 7 miles in the Okeechobee-St. Lucie Canal should be the limit.