canals to the fields. The smaller the canal or ditch, the steeper becomes its slope, and in the final application to the crops the flow in the furrows is often normal to the contours of the surface. In a river system the brooks feed the creeks, and the creeks feed the river, the flow being from the smaller to the larger; in an artificial irrigation system, however, the flow is from the larger to the smaller channel.

Seepage into the earth from an irrigation canal constantly goes on, unless its bed be puddled with clay or lined with concrete, and this loss of water is often very heavy. For new canals it is often as high as 50 percent of the water, but for old canals it may become lower than 10 percent. In making estimates for an irrigation supply it is hence necessary to take into account this seepage loss, and also to consider that due to evaporation.

Prob. 144. If all the rainfall that does not evaporate flows into the stream, find the runoff in cubic feet per second from a watershed of 1225 square miles during a month when the rainfall is 3.6 inches, the mean annual temperature being 48°.5 Fahrenheit. Also for the temperature of 49°.5.

Art. 145. Estimates for Water Supply

The consumption of water in American cities is, on the average, about 100 gallons per person per day, the large cities using more and the small ones less than this amount. The daily consumption in July and August is from 15 to 20 percent greater than the mean, owing to the use of water for sprinkling, while during January and February it is also greater than the mean in the colder localities, owing to the large amount that is allowed to run to waste in houses in order to prevent the freezing of the pipes. On Mondays, in small towns when every household is at work on the weekly washing, the consumption may be put at 50 percent higher than the mean for the week. Accordingly if the yearly mean be 100 gallons per person per day, the Monday consumption during very hot or very cold weather may be as high as 150 gallons per person per day. When a large fire occurs, the hourly consumption for this purpose alone in a fire district of 10 000 people may be at the rate of 175 gallons per person per day. In general the maximum available hourly supply should be from three to four times as great as the mean daily consumption.

When water is to be pumped from a river directly into the pipes, without tank or reservoir storage, the capacity of the pumps should be such that during the occurrence of fires at least three times the mean daily consumption may be furnished. When a pump delivers water to a distributing reservoir, its capacity need not be so high as in the case of direct pumping, for the reservoir storage can be drawn upon in case of fire. When the reservoir is large, the pump capacity need be only sufficient to lift the annual consumption during the time when it is in operation. The subject of pumping is an extensive one, but it will be briefly treated from a hydraulic standpoint in Arts. 192–201.

Gravity supplies are those obtained by impounding the runoff of a watershed at an elevation sufficiently high so that the water will flow without pumping to the places where it is to be consumed. Pumped supplies are obtained either from a stream which lies too low to furnish the water by gravity or from the ground from water-bearing strata which may be termed natural underground reservoirs. Such areas in a sandy country may yield as high as 1 000 000 gallons per day per square mile. The borough of Brooklyn of the City of New York obtains its water from the sands of Long Island, and a good example of the methods to be followed in estimating on such a supply is to be found in a report by Burr, Hering, and Freeman.*

In estimating on the safe yield of a surface watershed a study of the existing rainfall and stream flow data should be made. In the absence of the latter, estimates of the flow may be made by considering the rainfall records and computing the evaporation after allowing for all of the causes by which it is influenced. In some cases it will be found that even few rainfall data are available, and it then becomes necessary to consider the records at the nearest points where such observations have been made, and deduce values for the rainfall in the locality being considered.† In making estimates of this character all evidence should be carefully considered in order to avoid errors.

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* Report on Additional Water Supply, New York, 1903.

† Monthly Weather Review, March, 1907.

When gagings of the stream being studied are available,* the problem is a simpler one, but the period during which the gagings were taken must be examined with reference to its relation with the rainfall cycle (Art. 142). The results shown by such a series of gagings during a period of high rainfall would differ materially from those during a low cycle. This consideration is of particular importance when determining on the storage required for a water supply or for a power plant on a stream of moderate size, while on larger streams the controlling factor is often simply the quantity and duration of the minimum flow. This minimum is generally less dependent on the rainfall cycle than is the total yearly yield of the stream.

Having determined on the quantity of water to be supplied and on the flow for a series of years of the stream from which the water is to be obtained, it becomes necessary to fix on the volume of storage which will be necessary to tide over the driest period which is likely to occur. For this purpose the method proposed by Rippl † is a convenient one. It consists essentially in determining the net available stream flow for each month, after making allowances for evaporation from the reservoir surfaces which will result from the new construction and for all other possible losses. The total flow for each month is then added to the total of the months preceding and since the beginning of the period being studied. The total flow from the beginning of the period to the end of each month is thus determined and may be plotted as in Fig. 145*a*. The inclination of the curve *AM* joining the points so plotted thus represents the rate of net available stream flow, and may on occasion have a negative value as at *EI*, when the evaporation, leakage, and other losses are larger than the quantity of water available in the stream.

The amount of water to be used is now plotted as the line *AB*, it being assumed that the use is at a practically constant rate. Wherever the inclination of the curve is greater than that of the line *AB*, the net stream flow is greater than the draft, and wherever it is less the draft is in excess of the available water. To determine the amount of storage necessary to tide over such a period of deficiency, *EI*, if the line *EF* be drawn parallel to *AB* and tangent to the curve at *E*, the maximum ordinate *HI* will, on the scale

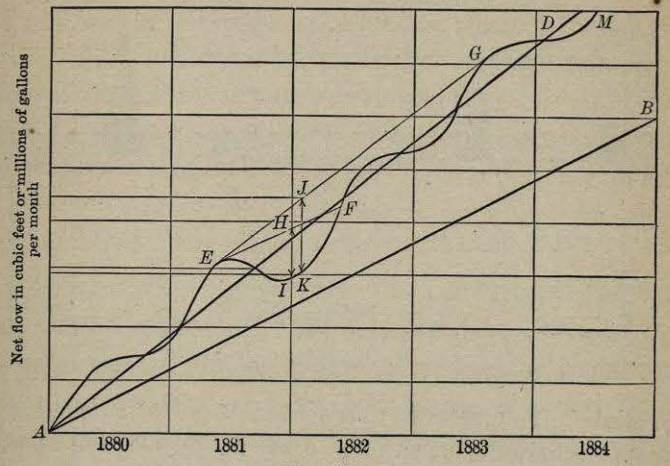

Fig. 145*a*.

of the diagram, indicate the amount of water which would have been necessary to maintain the uniform rate of draft as indicated by the line *AB*. Similarly if *AD* were the uniform rate of draft, the maximum ordinate *JK* between *EG*, drawn parallel to *AD*, and the curve would represent the storage volume necessary to maintain the draft *AD* from *A* to *G*. The maximum uniform rate of draft which could be obtained from *A* to *G* would be represented by the inclination of the line *AG*, but this rate, as also *AB* and *AD*, could not be constantly maintained unless the necessary storage was available at the beginning of the period at *A*. In case the tangent to any summit of the curve and parallel to the assumed rate of draft should fail to intersect the curve, it would be indicated that the draft was in excess of the total yield for the period under consideration.

Another graphical method is to plot the summation of the monthly differences between the net stream flow and the assumed uniform draft. In Fig. 145*b* if the reservoir be assumed to be full at the beginning of the period, then for the next three months the stream flow exceeds the draft and an overflow occurs as indicated above the zero line.

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* Transactions American Society Civil Engineers, vol. 59.

† Proceedings Institution Civil Engineers, vol. 71.

Above this line the actual amount of overflow in each month is plotted. At the end of the three months the draft begins to exceed the net stream flow and the reservoir level falls, as indicated by the continuous line. By the early part of the year 1891 the reservoir has again filled. The process is thus continued, and it is found that to tide over the period 1890 to 1894, if the reservoir be full at the beginning, a storage capacity of 3 billions of gallons is required.

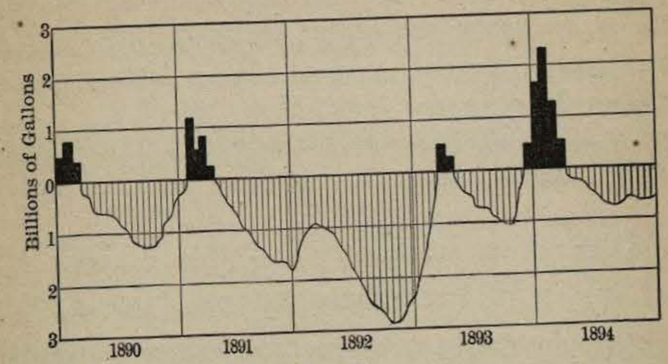

Fig. 145*b*.

The necessary volume of storage having thus been determined, it is usual in proportioning the reservoir to make an allowance to cover the uncertainties in the data as well as to provide a factor of safety against the occurrence of drier years than those covered by the records. Such an allowance may range from 10 to 50 percent of the storage as determined by the methods of Figs. 145*a* and 145*b*.

The quantity of storage necessary is dependent on the proposed rate of draft, but in general it may be said in the northeastern part of the United States, on rainfalls of from 38 to 50 inches, that a storage capacity of 250 000 000 gallons per square mile of watershed will permit of a safe uniform draft of from 600 000 to 900 000 gallons per square mile per day, the smaller figure being applicable to flat watersheds of low rainfall and the larger to those which are steep in slope and have higher rainfall.

After the height of the water level of the reservoir is fixed, the dimensions of its waste weir may be computed from Arts. 69 and 144 and the size of the main pipe line by Art. 97. For the latter computation proper pressures must be assumed throughout the town, so that ample head may be provided for fire contingencies. When the main divides into branches, the problem of computing the diameters from the given data is indeterminate (Art. 105), and hence it will probably be as well to assume at the outset the sizes of the main and its branches. The velocities corresponding to the given quantities and the assumed sizes being first computed, the pressure-heads at a number of points are found. If these are not satisfactory, other sizes are to be taken and the computation is to be repeated. The successful design will be that which will furnish the required quantities under proper pressures with the least expenditure.

Prob. 145. How many cubic feet per second per square mile are equivalent to a rainfall of one inch per month?

Art. 146. Estimates for Water Power

The methods of estimating the water power that can be derived by damming a stream are to some extent similar to those for water supply. In the absence of gagings the records of rainfall and evaporation are to be collected and discussed, but a few gagings will probably give more definite information if records of water stages during several years can be had. A method of determining the advisable extent of a water power development when records of stream flow are available has been developed by Herschel.*

In nearly every situation the stream flow in connection with the storage which can be obtained at a reasonable expense is not sufficient to continuously generate the power which is required. In such cases it is necessary to supplement the water power with an auxiliary steam plant located at some point within the territory to be served where fuel can be obtained most economically. In order to determine on the capacity of such an auxiliary plant the general method shown in Fig. 145*a* may be used. With the known volume of available storage and net flow of the stream the maximum uniform rate of draft can be determined. The capacity of the auxiliary steam plant may then be considered as the difference between the power capacity required and that furnished by the minimum flow of the stream; while the advisable extent of the water power development will depend upon considerations of the river discharge, the cost of

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* Transactions American Society of Civil Engineers, 1907, vol. 58, p. 29.

the development, and the cost of installation and operation of the auxiliary steam plant. No definite rules are to be laid down in this regard, as the exact proportion to be finally decided upon depends on many factors which vary in every locality.

The power needed to be generated by a plant varies from hour to hour. The greatest demand is called the "peak." A peak load is one of very short duration and can be met by installing an excess of turbine and generator capacity and by providing storage in a pond of adequate size. It is probable, however, that in many cases the auxiliary heat engines already installed to meet low water conditions will more economically supply the power for the peak loads than would the necessary excess turbine, generator, power house and storage capacity.

At times of high water the head on the wheels is often reduced, due to the change in slope of the river, and the normal output of the plant is thus diminished. The "fall increaser" (Art. 181) will operate to increase the available head, or where this is not provided the auxiliary steam plant must be called on to supply the deficiency.

Let W be the weight of water delivered per second to a hydraulic motor, and h be its effective head as it enters the motor, h being due either to pressure (Art. 11), or to velocity (Art. 22), or to pressure and velocity combined (Art. 24). The theoretic energy per second of this water is

$$K = Wh \qquad (146)_1$$

and if W be in pounds and h in feet, the theoretic horse-power of the water as it enters the motor is

$$\overline{HP} = Wh/550 \qquad (146)_2$$

and this is the power that can be developed by a motor of efficiency unity. The work k delivered by the motor is, however, always less than K, owing to losses in impact and friction, and the horse-power $\overline{hp}$ of the motor is less than $\overline{HP}$. The efficiency of the motor is

$$e = k/K = k/Wh \quad \text{or} \quad e = \overline{hp}/\overline{HP} \qquad (146)_3$$

and the value of this for turbine wheels is usually about 0.80; that is, the wheel transforms into useful work about 80 percent of the energy of the water that enters it.

In designing a water-power plant it should be the aim to arrange the forebays and penstocks which lead the water to the wheel so that the losses in these approaches may be as small as possible. The entrance from the head race into the forebay, from the forebay into the penstock, and from the penstock to the motor should be smooth and well rounded; sudden changes in cross-section should be avoided, and all velocities should be low except that at the motor. If these precautions be carefully observed, the loss of head outside of the motor can be made very small. Let H be the total head from the water level in the head race to that in the tail race below the motor. The total available energy per second is WH, and it should be the aim of the designer to render the losses of head in the approaches as small as possible so that the effective head h may be as nearly equal to H as possible. Neglect of these precautions may render the effective power less than that estimated.

The efficiency e_1 of the approaches is the ratio of the energy K of the water as it enters the wheel to the maximum available energy WH, or $e_1 = K/WH$. The efficiency E of the entire plant, consisting of both approaches and wheel, is the ratio of the work k delivered by the wheel to the energy WH, or

$$\text{E} = k/WH = eK/WH = ee_1$$

or, the final efficiency is the product of the separate efficiencies. If the efficiency of the wheel be 0.75 and that of the approaches 0.96, the efficiency of the plant as a whole is 0.72, or only 72 percent of the theoretic energy is utilized. Usually the efficiency of the approaches can be made higher than 96 percent.

In making estimates for a proposed plant, the efficiency of turbine wheels may generally be taken at 80 percent; the effective work is then $0.80Wh$, and accordingly if the wheels are required to deliver the work k per second, the approaches are to be so arranged that Wh shall not be less than $1.25k$. Especially when the water supply is limited it is important to make all efficiencies as high as possible.

Prob. 146. A stream delivers 500 cubic feet of water per second to a canal which terminates in a forebay where the water level is 8.1 feet above the tail race. The wheels deliver 335 horse-power and their efficiency is known to be 75 percent. How much power is lost in the forebay and penstock?

ART. 147. WATER DELIVERED TO A MOTOR

To determine the efficiency of a hydraulic motor by formula $(146)_3$ the effective work k is to be measured by the methods of Art. 149, and the head h to be ascertained by Art. 148. In order to find the weight W that passes through the wheel in one second, there must be known the discharge per second q and the weight w of a cubic unit of water; then

$$W = wq$$

Here w may be found by weighing one cubic foot of the water, or when the water contains few impurities its temperature may be noted and the weight be taken from Table 3. In approximate computations w may be taken at 62.5 pounds per cubic foot. In precise tests of motors, however, its actual value should be ascertained as closely as possible.

The measurement of the flow of water through orifices, weirs, tubes, pipes, and channels has been so fully discussed in the preceding chapters, that it only remains here to mention one or two simple methods applicable to small quantities, and to make a few remarks regarding the subject of leakage. In any particular case that method of determining q is to be selected which will furnish the required degree of precision with the least expense.

For a small discharge the water may be allowed to fall into a tank of known capacity. The tank should be of uniform horizontal cross-section, whose area can be accurately determined, and then the heights alone need be observed in order to find the volume. These in precise work will be read by hook gages, and in cases of less accuracy by measurements with a graduated rod. At the beginning of the experiment a sufficient quantity of water must be in the tank so that a reading of the gage can be taken; the water is then allowed to flow in, the time between the beginning and end of the experiment being determined by a stop-watch, duly tested and rated. This time must not be short, in order that the slight errors in reading the watch may not affect the result. The gage is read at the close of the test after the surface of the water becomes quiet, and the difference of the gage readings gives the depth which has flowed in during the observed time. The depth multiplied by the area of the cross-section of the tank gives the volume, and this divided by the number of seconds during which the flow has occurred furnishes the discharge per second q.

If the discharge be very small, it may be advisable to weigh the water rather than to measure the depths and cross-sections. The total weight divided by the time of flow then gives directly the weight W. This has the advantage of requiring no temperature observation, and is probably the most accurate of all methods, but unfortunately it is not possible to weigh a considerable volume of water except at great expense.

When water is furnished to a motor through a small pipe, a common water meter may often be advantageously used to determine the discharge (Art. 38). No water meter, however, can be regarded as accurate until it has been tested by comparing the discharge as recorded by it with the actual discharge as determined by measurement or weighing in a tank. Such a test furnishes the constants for correcting the result found by its readings, which otherwise is liable to be 5 or 10 percent in error. The Venturi meter (Art. 38) furnishes an accurate method of measuring large quantities.

The leakage which occurs in the flume or penstock before the water reaches the wheel should not be included in the value of W, which is used in computing its efficiency, although it is needed in order to ascertain the efficiency of the entire plant. The manner of determining the amount of leakage will vary with the particular circumstances of the case in hand. If it be small, it may be caught in pails and directly weighed. If large in quantity, the gates which admit water to the wheel may be closed, and the leakage being then led into the tail race, it may be there measured by a weir, or by allowing it to collect in a tank. The leakage from a vertical penstock whose cross-section is known may be ascertained by filling it with water, the wheel being still, and then observing the fall of the water level at regular intervals of time. In designing constructions to bring water to a motor, it is best, of course, to arrange them so that all leakage will be avoided, but this cannot always be fully attained, except at great expense.

The most common method of measuring q is by means of a weir placed in the tail race below the wheel. This has the disadvantage that it sometimes lessens the fall which would be otherwise available, and that often the velocity of approach is high. It has, however, the advantage of cheapness in construction and operation, and for any considerable discharge appears to be almost the only method which is both economical and precise. If the weir is placed above the wheel, the leakage of the penstock must be carefully ascertained.

Prob. 147. A weir with end contractions and no velocity of approach has a length of 1.33 feet, and the depth on the crest is 0.406 feet. The same water passes through a small turbine under the effective head 10.49 feet. Compute the theoretic horse-power.

ART. 148. EFFECTIVE HEAD ON A MOTOR

The total available head H between the surface of the water in the reservoir or head race and that in the lower pool or tail race is determined by running a line of levels from one to the other. Permanent bench marks being established, gages can then be set in the head and tail races and graduated so that their zero points will be at some datum below the tail-race level. During the test of a wheel each gage is read by an observer at stated intervals, and the difference of the readings gives the head H. In some cases it is possible to have a floating gage on the lower level, the graduated rod of which is placed alongside a glass tube that communicates with the upper level; the head H is then directly read by noting the point of the graduation which coincides with the water surface in the tube. This device requires but one observer, while the former requires two; but it is usually not the cheapest arrangement unless a large number of observations are to be taken.

From this total head H are to be subtracted the losses of head in entering the forebay and penstock, and the loss of head in friction in the penstock itself, and these losses may be ascertained by the methods of Chaps. 8 and 9. Then

$$h = H - h' - h''$$

is the effective head acting upon the wheel. In properly designed approaches the lost heads h' and h'' are very small.

When water enters upon a wheel through an orifice which is controlled by a gate, losses of head will result, which can be estimated by the rules of Chaps. 5 and 6. If this orifice is in the head race, the loss of head should be subtracted together with the other losses from the total head H. But if the regulating gates are a part of the wheel itself, as is the case in a turbine, the loss of head should not be subtracted, because it is properly chargeable to the construction of the wheel, and not to the arrangements which furnish the supply of water. In any event that head should be determined which is to be used in the subsequent discussions: if the efficiency of the fall is desired, the total available head is required; if the efficiency of the motor, that effective head is to be found which acts directly upon it (Art. 146).

When water is delivered through a nozzle or pipe to an impulse wheel, the head h is not the total fall, since a large part of this may be lost in friction in the pipe, but is merely the velocity-head $v^2/2g$ of the issuing jet. The value of v is known when the discharge q and the area of the cross-section of the stream have been determined, and

$$h = v^2/2g = (q/a)^2/2g$$

In the same manner when a stream flows in a channel against the vanes of an undershot wheel the effective head is the velocity-head, and the theoretic energy is

$$K = Wh = Wv^2/2g = wq^3/2ga^2$$

If, however, the water in passing through the wheel falls a distance h_0 below the mouth of the nozzle, then the effective head which acts upon the wheel is given by

$$h = v^2/2g + h_0$$

In order to fully utilize the fall h_0 it is plain that the wheel should be placed as near the level of the tail race as possible.

Lastly, when water enters a turbine wheel through a pipe, a piezometer may be placed near the wheel entrance to register the pressure-head during the flow; if this pressure-head, meas-