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Paper No. 1722

STREAM FLOW IN GENERAL TERMS*

By MELVIN D. CASLER,† M. AM. SOC. C. E.

WITH DISCUSSION BY MESSRS. FRANK S. BAILEY, CECIL E. PEARCE, F. THEODORE
MAVIS, MORROUGH P. O'BRIEN, R. D. N. SIMUAM, AND MELVIN D. CASLER.

SYNOPSIS

The purpose of this paper is to present a workable general method for the analysis of stream flow in irregular channels—channels in which the invert slope and the channel cross-section are not constant. To attempt to apply the Chezy formula to such a case is to force a perfectly good formula into a situation to which it is not properly applicable. Various scattered attempts have been made to treat this question as applied to special cases, but no satisfactory general treatment has been found in such a form as to be readily followed by most computers.

An exhaustive consideration of the subject of "back-water curves" is contained in "Technical Reports," Part III, of The Miami Conservancy District, but this discussion is confined to "rectangular channels the width of which is uniform and so great in comparison with the depth that the hydraulic radius may be considered equal to the depth."

The discussion contained in this paper is general, and demonstrations of its applicability to weirs, orifices, and siphons are appended.

The Chezy formula, $v = C \sqrt{r s}$, is the one most commonly used in stream-flow computations. The factor of longitudinal slope, s , is sometimes referred to as the slope of the water surface and sometimes as the slope of the bed of the stream. As a matter of fact, it is neither of these except under special conditions. The Chezy slope factor should be defined as the friction factor, or rate of loss of head. This is equal to the slope of the water surface

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† Mount Vernon, N. Y.

ground-water inflow. As the stream emerges from the mountain canyons into the lower valley, it often flows for some distance over a delta or cone where the adjacent ground-water level is lower than the water level in the stream, and where the natural channel loses water at all stages. Farther down stream the ground-water may again rise higher than the water level in the stream, resulting in a ground-water inflow, and it may then gain to the stream in such sections. On numerous Western streams such alternate sections of gain and loss occur for many miles.

In sections where the stream loses water due to the adjacent water-table being lower than the level in the stream, the stored water should manifestly be charged with the additional loss created by carrying it, as compared with what the natural loss would be without including the stored water. The practice of determining percentage losses in the channel with both stored water and natural flow in the stream, while supplying information of interest, should not be relied on entirely to determine proper losses chargeable to stored water. A comparison of losses with natural flow alone, and when carrying the additional stored water should also be made. Studies of the ground-water flow through the valley must necessarily be made to determine whether the water lost in the "loss" sections of the stream returns farther down stream as gain and, if so, when and where such return takes place. Stored water is properly entitled to credit for whatever portion of the "lost" stored water that returns to the stream above diversion points during the period of full use of the stream flow each year. In some of the larger river valleys of the West, this "lost" water requires several years to complete its underground travels and finally emerges as ground-water or spring inflow into the stream. Thus, the continual carrying of stored water for year after year may result in that portion of such stored water that is lost in the "loss" sections, finally re-appearing as a permanent increase in the gain to the stream in the "gain" sections.

In sections of the stream where the water-table is higher than the water level in the stream channel, the stored water sustains little actual loss, but it has the effect, when first turned in, of damming back part of the natural ground-water inflow until the ground-water slopes adjacent to the stream re-adjust themselves to the higher water level in the stream occasioned by the stored water. The effect of running stored water in such sections of natural gain from ground-water inflow to the stream can best be studied by noting the reduced gain for a short period, varying under different conditions from a few days to several weeks, when stored water is first turned into the channel. This temporary bank storage returns rapidly to the stream when the stored-water run ceases and the stream drops to its natural level. In the delivery of stored water on Big Lost River, the matter is adjusted by allowing the natural flow rights to use some of the stored water during the first week that it is turned into the stream, the same quantity being repaid to the stored-water owners later in the season from the increased gain that occurs for a brief period when the stored-water run ceases.

As pointed out by Mr. Baldwin, the matter of the equitable segregation of stored water and natural flow is a complicated one in many cases. It is not subject to exact determination on account of differences in climatological

factors, ground-water levels, stream channel conditions, etc., from year to year and at different times during the same year. By securing records covering a number of years on inflow, diversions, and losses along the stream, together with studies of the ground-water movements, however, a basis may be developed for an intelligent study of the question, and a fair approximation may be thus reached for the determination of the natural flow and stored water, as each is delivered to its respective owners.

THOMAS R. NEWELL,* Assoc. M. Am. Soc. C. E. (by letter).—An outline of the methods used in transmitting and delivering reservoir water in Water District No. 36, Idaho, has been presented by Mr. Baldwin. It is mentioned that transmission is effected through the Snake River channel from both the Jackson Lake and American Falls Reservoirs to the river head-gates of the numerous owners of storage rights. Thus, the channel of the main river carries an increment of reservoir in addition to the current run-off of the water-shed during a large part of the irrigation season. Natural water distribution must be made simultaneously with storage delivery despite the complications introduced by mingling this current run-off with these continuous streams of transit storage. In some sections of the river the reservoir water increment is even greater than the natural flow during part of the season. The relative proportions vary for years of differing snow supplies and irrigation demands.

Transmission loss schedules and reservoir outlet divisions always must meet the tests of changing conditions and even of changing ownerships. The small percentage of ultimate wastage (flow past Milner Dam during regulation period) is a real index of the excellence and efficiency of the control system of river operation as a whole. The fact that these major reservoirs have been operated ever since their construction in conjunction with natural water distribution from the same water-shed, through identical delivery channels and without the authority of a Court Commissioner, speaks well for the efforts of the administrative official and perhaps also for the tolerance of district water users.

The compromise agreements upon which division is made between natural and reservoir waters when flowing commingled are of particular interest to the writer. In Water District No. 36 these agreements consist of brief digests of methods of division at reservoir outlets and schedules of percentage transmission losses to be applied through successive river sections to transit storage. As they are adopted annually in slightly revised form, these compromise schedules should carry greater prestige from year to year, and as time goes on, should become more nearly representative of true conditions. It is readily seen that variations in these schedules directly affect the quantity of reservoir delivery. In like manner, changes affect the total supply of natural water in the opposite direction. Even now basic changes are stubbornly conducted and are almost impossible of adoption without recourse to hydrological investigations of a co-operative nature. Objections of merit are usually met by secondary arrangements or the granting of special privileges to avoid upsetting standard compromise schedules.

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In this connection it is interesting to note the exact effect of a change in a river operation agreement from the viewpoint of a holder of a natural water decree and a user of reservoir water. Assume, for example, that a transmission loss schedule is increased 10 per cent. Each storage owner's holdings are decreased 10 per cent. The only escape he has from the penalty is that his storage right may be a mere insurance and seldom withdrawn. This same increase in applied transmission loss increases the total supply of natural water, but not *pro rata* to each holder of a decreed right. In Idaho, a decreed right specifies a quantity (if beneficially used) and, in all cases, a priority date. As river supplies decrease below the quantity necessary to fulfill all decrees in use, the river water master refers to his chronological list of priority dates and declares that right with the latest date either partly or completely invalid and denies use thereunder. This process of eliminating one user after another is continued until the river stage reaches the summer low. Then, as supplies increase, each decree is restored in reverse order.

Pioneer rights to the extent of the minimum summer flow remain untouched and, in reality, have no interest in the changed transmission loss. The younger the right the longer is the period of denied use which must be suffered. To each invalidated right an increased transmission loss means an extended time of validity at either end of its period of denied use. The length of the extension is defined by the amount of gain to natural supplies due to the changed schedule and the rate of river decline or increase. It may not encompass the whole decree and it may not help for more than a single day; but for several years the storage delivery rate from the Jackson Lake Reservoir has been quite large during the months of July and August. Likewise, the summer minimum of Snake River flow usually remains fairly constant for several weeks in the height of the irrigation season. Therefore, it is possible for a single large decree, properly placed along the chronological scale, to garner a lion's share of the total increase in natural supplies resulting from a changed transmission loss.

To carry the illustration still further, it is true that many of these young rights have purchased supplemental storage, so that their gains may be partly offset by losses to their supplemental supplies. Careful study of these effects serves to accent the fallacy of the popular belief that any general method of division between the two classes which balances for the season is fair to the individual decree holder. It may also present to the politically minded an interesting angle of the "ins and outs" of stipulative agreements.

Compromise river and reservoir agreements should tend toward workable methods of division which should be fair to each party throughout each season and which should keep pace with current events. With the initial draft from the new American Falls Reservoir comes a series of changed ownerships, new river complications, and notable variations in river regimen extending from Jackson Lake all the way to Milner. A reservoir outlet division, operated on the contour method, in which evaporation losses and natural storage credits are balanced against bank storage return, usually contemplates a full use of the reservoir and cannot be expected to serve a hold-over storage unit. Henrys Lake Reservoir is notably in the latter class and on account of recent

changes in ownership at Jackson Lake, this great storage unit is tending in that direction.

These same factors operate toward less regular increments of reservoir water being carried through the main river channel. Flat percentage rates of transmission loss and flat time interval allowances for any and all river stages and rates of delivery will not so fairly comprehend the new situation. Lag credits help to even the charges, but should be applied in direct proportion to increases in stage and should not be permitted to be used in any but a regular mechanical manner. The space privilege, the temporary transfer, and many permanent transfers might each serve an honest purpose did they not so often go hand in hand with appropriation and even Court decree beyond the bounds of beneficial use. The current dearth of water supply in Water District No. 36, due to the many new storage purchases (made possible by the construction of the American Falls Reservoir, and the ample natural run-off of 1927 and 1928), has eased the river operation situation temporarily. The advent of a season of shortage will not soon bring general crop losses on account of the presence in the district reservoirs of much "water insurance" which may be rented; but with the reclamation of additional lands, now contemplated, supplies will eventually be depleted to the point where river and reservoir problems will become more important.

Only a part of the transmission and division agreements now in force have support in actual seepage investigations. Of these investigations, many have been continued during one season only, while some are based only on miscellaneous field runs. Continuity through different types of seasons—the fundamental of every thorough hydrological study—has been denied in most cases. Few, if any of the channel studies made in the past, show the application of the modern methods of refining river-station differences in use in California and some even ignore surface tributary inflow as an independent variable. The Kootenai River study now in progress (1928) on the International Boundary has been planned with a view to obtaining a degree of refinement far beyond that of any lake or reservoir segregation yet made in this district. The criticism often heard, to the effect that the segregation of the many factors involved can never be exact, is true despite the use of the most modern methods economically feasible.

However, real values do result from orderly presentation of measurable factors properly qualified as to exactitude. Just divisions require careful observation of seasonal trends of disputed factors. Developed waters resulting from drainage recoveries, return flows from new irrigation, artificial ground storage, and reservoir bank storage, should each be observed currently. Changed plans for reservoir drafts due to changing ownerships should not be overlooked. All in all, too much should not be expected of old and insufficient investigations, and every effort should be made to make the new ones more thorough and continuous. The effort to centralize and co-ordinate all administrative activities, within the district, has built up a continuing and an adequate organization which has effected improved operation service. The basic schedules underlying operation schedules are entitled to equal consideration and support.

To the student of river operation, Mr. Baldwin's paper is particularly interesting, in that it is representative of ten years' experience in transmitting reservoir waters at rates of much greater magnitude than usual. The same rules which apply to storage deliveries at the rate of a few miner's inches for a few miles are entirely inadequate in transmitting reservoir water by the thousands of second-foot for hundreds of miles to the respective owners. It is to be regretted that more detail has not been included for a careful description of the very effective system of control which has resulted in uninterrupted service and, at the same time, a negligible ultimate waste. The attainment of these two ends is the mark of good regulation and deserves the careful consideration of every person interested in orderly distribution on a large scale.

E. B. DEBYER,* M. Am. Soc. C. E.—The State of California adopted riparian rights as the basis of its water rights many years ago, and as no affirmative action on the part of the grantee was required, such rights became vested as to all riparian lands, with the action of the State Legislature.

Fundamentally, riparian rights imply non-consumptive uses only, but in the main the Courts have upheld any uses which did not deprive other riparian owners of their proportionate share of such use.

Recent attempts to impose limitations on the use of these riparian rights, even if only in support of a more efficient use of the State's water resources, either by legislative enactment or by regulations of an administrative arm of the State Government, are likely to prove fruitless as they would appear to be in the nature of confiscation of a vested property right which the Courts will not sanction. In view of this situation, plans for the conservation of the water resources of the State must be placed on a sounder legal basis.

The situation with regard to conflict of riparian and appropriation rights is not limited to California. Both types of rights exist in a number of Western States. Nebraska has adopted riparian rights for its humid section and appropriation rights for its arid section. Land grants by the Spanish Crown in the Southern Border States often carried water rights, sometimes distinctly "appropriation" in character, at other times, "riparian." The outcome of California's attempts to curb riparian rights will be watched with interest, as it is likely to be followed in after years by similar attempts in other States when water becomes of greater value.

G. CLYDE BALDWIN,† M. Am. Soc. C. E. (by letter).—Discussion of the writer's paper has very properly not been limited to the problems incident to the transmission and delivery of water from Snake River reservoirs. Mr. Hinderlider has presented an excellent summary of the methods used in the State of Colorado and has listed eight so-called requisites for equitable and efficient water administration which, with possibly slight modification, should be generally applicable.

The extent to which transmission losses are increased by "adverse-user" diversions, together with the accessibility of their head-gates, obviously will

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determine the degree of regulation which should be enforced. For example, it would probably be unwise to attempt to prevent the use of water by isolated canyon ranches unless the resulting benefits to be derived by the owners of older rights would be sufficient to justify the expense of the regulation.

Mr. Meeker emphasizes the desirability of continued, comprehensive, engineering investigations and reports as an aid to better administration, and this is also stressed by Mr. Newell. Both, however, recognize the variable, complex character of the different factors on which the stream flow at any given point depends, and they understand that exact solutions of river or reservoir loss problems can never be attained.

Engineers usually are anxious to secure an increasing amount of data on such subjects in order to minimize the always recognizable error in the final application.

From the practical viewpoint of the ordinary water user, on the other hand, extreme accuracy seems less essential, especially if the engineering investigations must be done at his expense. Furthermore, in such extremely complicated problems as those on Snake River, the same basic facts may be used sometimes in good faith by different engineers to derive somewhat divergent conclusions. The water users, therefore, as a group, are rather slow to adopt radical changes in methods of operation and prefer to follow the usage of preceding years, with perhaps slight modifications based on new facts, rather than to sanction expenditures for engineering investigations which may result in controversy.

As mentioned by Mr. Crandall, segregation of stored water and normal stream flow at the outlets of reservoirs and the schedule of losses to be charged the former while in transit in the stream channel between the reservoirs and points of diversion are usually the two principal sources of contention in river administration.

The desirability of having these points settled by Court order or decree has long been recognized by those most interested in the storage and delivery of water on Snake River, and much has been accomplished through special studies and investigations with that end in view. At present (January, 1929), reports covering ground-water conditions along Snake River and the 1928 gains and losses in the American Falls Reservoir Basin are in process of preparation.

The net result of more than ten years of river operation has been the plan described in the paper which, as modified from time to time to meet new conditions or to be more consistent with added facts as they became available, has now, through precedent, attained a position almost comparable to, and may eventually be converted into, a Court order through stipulation by the interested parties.