PLANNING ADVANCED STREAM-GAGING PROGRAMS

John E. McCall

District Engineer, U. S. Geological Survey
Trenton, New Jersey

INTRODUCTION

Two weeks ago at Cape Canaveral, Florida, a stirring event in the conquest of space was in preparation. You will recall some of the complexity of the planning, arrangements and instrumentation for the first orbital flight by an American. The news coverage alone must have cost millions of dollars, not to mention the scientific and technological effort devoted to this project. Yet only thirty minutes before blast-off no one could predict with certainty whether light clouds overhead would clear away before the count-down was completed or not. As it turned out the cloudiness increased instead and the whole operation had to be postponed.

Man may never be able to modify the weather effectively, though some small strides have been made in this direction. Certainly man can never control it until he completely understands the mechanics and physical processes involved in climate and weather. Modern science is rapidly advancing the frontiers of knowledge in meteorology and hydrology, both of which are still very young disciplines of study. Yet for every right answer achieved it seems that two new questions emerge. Fortunately, the magnitude of the new questions is usually much smaller than the one solved, so that gradually the pyramid of knowledge heads toward an apex. Even though the pinnacle of knowledge will never be reached, it is reassuring to note the ever broadening base of facts and understanding available.

So it is with stream-gaging programs, which represent one slice or part of the science of hydrology, which in itself is only a narrow segment in the growing circle of scientific knowledge. Even in the limited field of streamflow only the more obvious phenomena are fully understood in 1962.

ESTABLISH GOALS

If engineers or scientists are to predict the consequences of alternatime courses of action, they must first comprehend the mechanics and basic laws of the natural system that they seek to modify. As stated by Hendricks 1/ "Those of us who are concerned with hydrologic technology seek to understand hydrologic processes and the interplay of hydrologic factors so that we can predict the consequences of a change that may affect water resources. A large part of our effort in hydrologic research is directed toward that ultimate objective. We need to be able to predict accurately the hydrologic effects of changes that are made on the land. We must be able to predict for a given locality the effects of increased groundwater withdrawals on streamflow. We must know both the hydrology and the geology of reservoir sites well enough to predict both the local and the far reaching long-range effects of a reservoir or a system of reservoirs".

The resource planner's ultimate target or goal, then, should be the complete description and understanding of the resources with which he is dealing; in the present instance, surface-water resources. He must, of course, attempt to put first things first and to maintain a perspective as to what is more important now, as compared to 5 or 10 or 100 years from now. Yet the planner can afford to be a little more imaginative and less "down-to-earth" than the administrator or the operations chief, for he especially is charged with looking into the future. The others may veto or defer his plans because of practical difficulties, but the planner has the duty to project beyond today's actuality into the possibilities and alternatives of an uncertain tomorrow.

DEVELOPMENT OF NETWORK

In planning a brand new stream-gaging program for an undeveloped country, say in darkest Africa, the beginnings would be small. Perhaps a staff gage on the largest rivers, to be read once or twice daily by the local residents or town officials, plus a few rain gages.[2/] [3/] But in the situation facing the participants in the Eastern Snow Conference, the planner is dealing with a much more advanced and sophisticated problem. For the stream-gaging programs in eastern United States and southeastern Canada have progressed over many years, particularly since about 1930, to the point that much is known about the rivers and lakes.[4/] At the same time the pressures of an expanding population, growing industry, and accompanying effects of urbanization have created the need for more detailed and more refined information. Such advanced information might be unnecessary and unjustified, at present, in the Congo or even Newfoundland or Wyoming, yet be long overdue in New York or Ontario.

The following discussion will be limited to such refinements and advanced phases of planning as might apply to stream gaging programs in highly developed regions. It will be assumed, for example, that network planning undertaken in recent years both in the United States[5/] and Canada[6/] has progressed to the operational stage already. The networks would include a small number of permanent gaging stations surrounded by a larger number of temporary stations and partial-record sites.

The existing network in the Raritan River basin in New Jersey is shown in fig. 1. Note there are only three primary stations in this basin of about 1100 square miles. There are, however, seven secondary or temporary stations. The six stations shown with a solid circle are "water management stations". Most of these are below diversions and do not measure natural or "virgin" flow but are needed for control and management of the water resources. Although these are permanent and accurately calibrated stations they generally cannot be used in the hydrologic network because they measure artificially regulated flows.

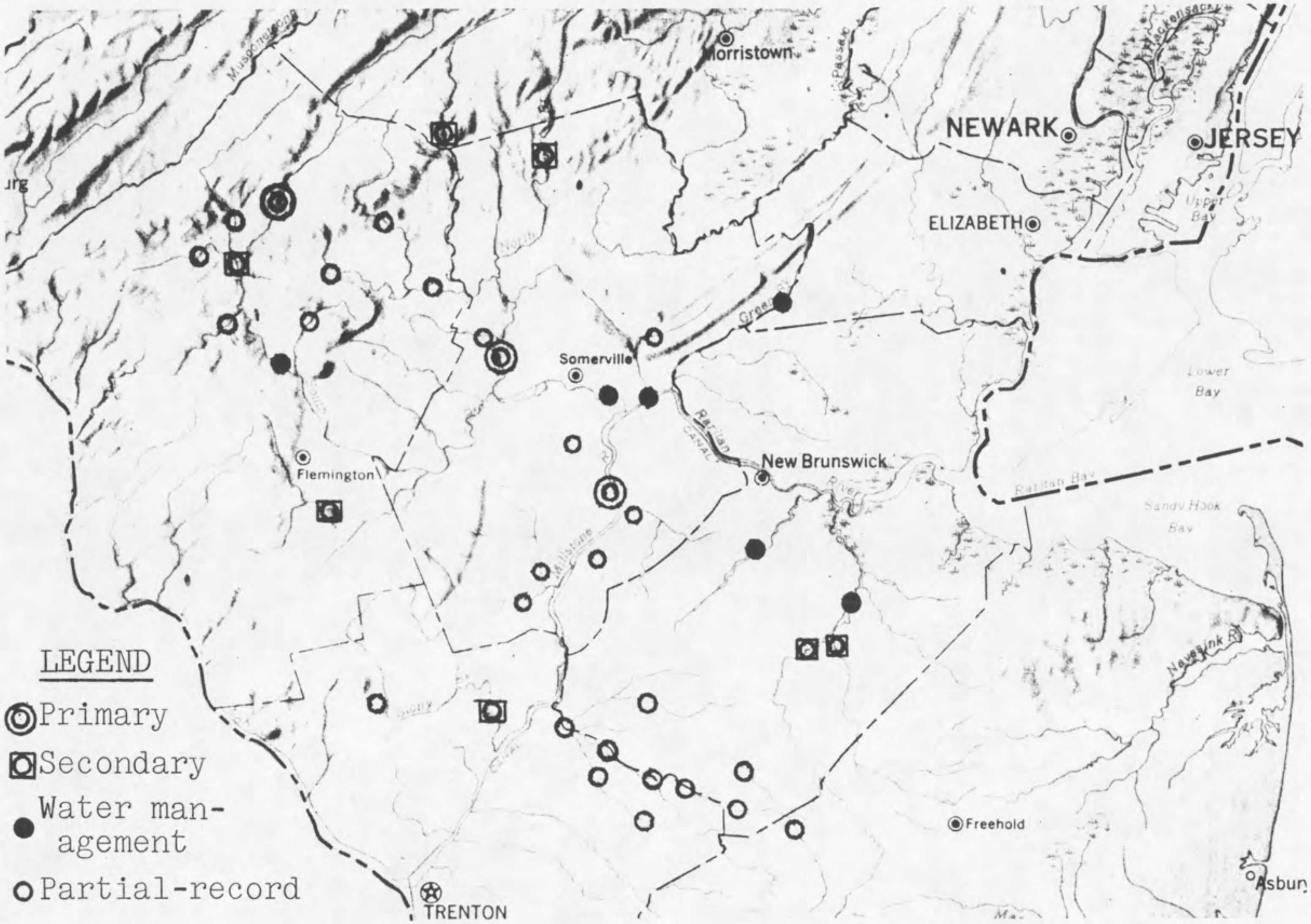

Figure 1.--Map of stream-gaging network in Raritan River basin, New Jersey.

The 25 small open circles represent low-flow partial-record stations. Here no recording gages are installed but discharge measurements are systematically made during base flow conditions (no rain for 3 to 5 days preceding) in the spring and fall for several years. The simultaneous flow at a secondary or primary gaging station nearby is used to develop a correlation between the flows at the two sites. By this correlation the low-flow or mean flow at the partial-record station can be estimated for other days or other periods. Similarly the short record at a secondary station can be extended by correlation with a primary station record.

The extent of scatter or conversely the degree of confidence in these correlations varies widely. In humid regions the correlations are usually fairly good and will meet many practical purposes. In arid regions of extremely diverse hydrologic environment frequently they are of much less value. For use in arid regions and for more detailed or refined study in humid regions, a relatively new extension of the network concept has emerged recently. This is descriptively termed "river-system-gaging", consisting of simultaneous measurements throughout a basin.

RIVER-SYSTEM-GAGING

Picture if you will the simultaneous flow at all points in a river basin. Figure 2 illustrates this, showing the average flow as determined from all the gaging records in the Raritan River basin. Interpolation between gaged locations was done on the basis of drainage area. A similar diagram for minimum daily flow would show variations from less than one-half of one percent of the average to as much as eleven percent of the average flow at different gaging stations, with no apparent rhyme nor reason for the inconsistencies. It would not be safe to interpolate between gaged points with respect to minimum flows as was done for average flows.

Big increases in dry-weather flow may occur in some relatively short reaches where springs and ground-water seeps are numerous or where sewers discharge into the stream. On the other hand, some very long stretches of channel in an impermeable soil or geologic formation may have no pick-up in flow at all. In fact there are several ways, both natural and man-made, in which water can be lost to the flow of a stream. These include direct stream diversion for water supply and irrigation, pumping from nearby wells, under-flow through sandy or gravel streambeds or through crevices and solution channels in rock, evaporation from water surface and wetted bed and banks, and transpiration from trees, bushes, and grasses along the stream.

River-system-gaging gives a direct measure of any such effect big enough to be detected by a current-meter measurement of flow. The gaging proceeds during periods of base flow in the spring, summer or fall, when there is no snow, ice or frozen ground to distort results, and three to

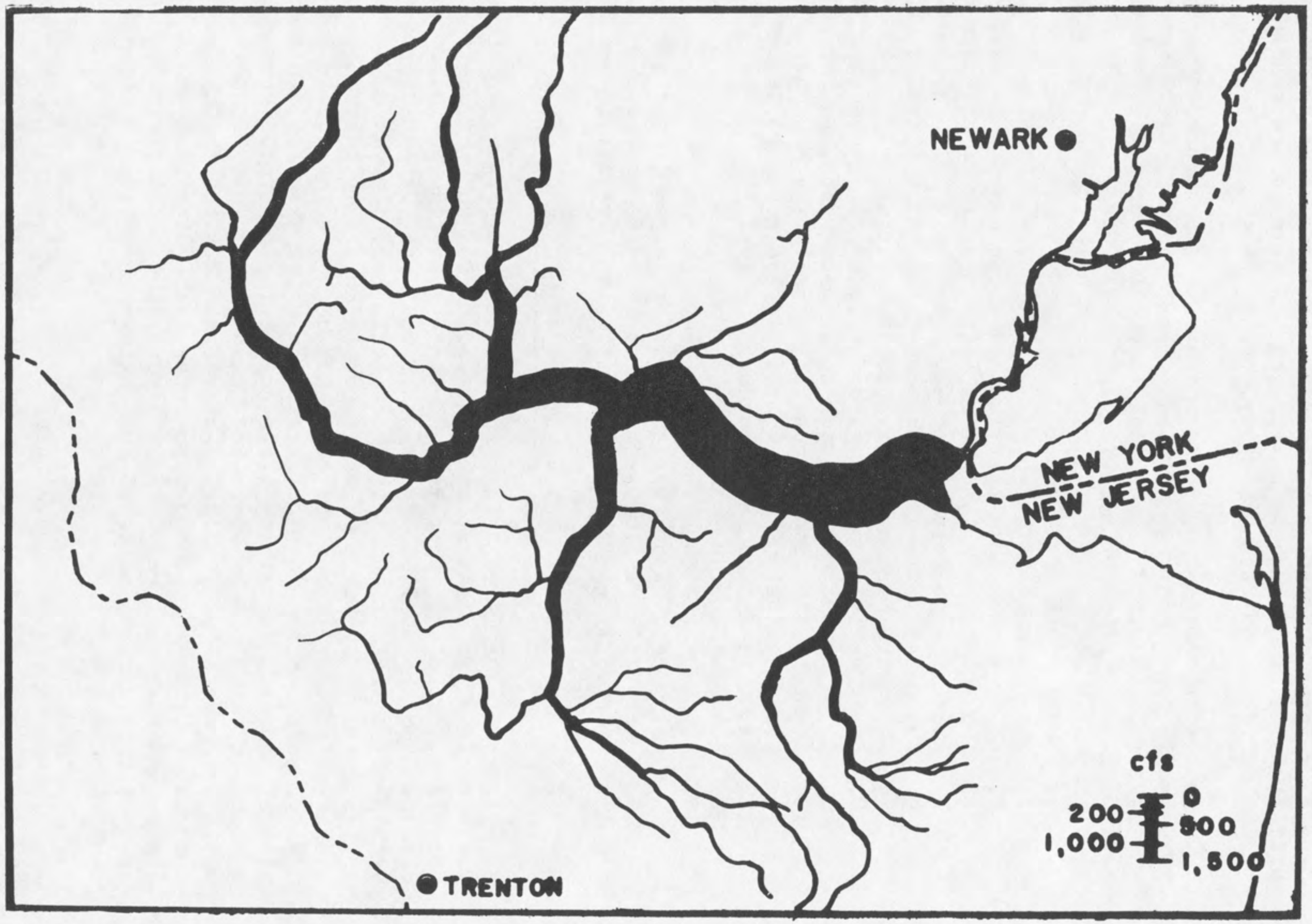

Figure 2.--Average streamflow in the Raritan River basin New Jersey.

five days after significant rainfall. As large a sub-basin is covered as the number of streamflow measuring parties will permit. Each man can measure from four to eight locations per day in addition to collecting several samples of water for later chemical and sanitary analysis. Measurements should be computed on-the-spot to help detect conditions in the field that may require explanatory notes.

Approximate measuring locations are selected in advance by study of large-scale topographic and geologic maps. Advance field reconnaissance may save much valuable time during short-lived base flow conditions. The following are typical of measuring sites selected:

1. Above mouth, confluence or delta
2. Above head of tide
3. Above each important tributary (also measure or est. trib. flow)
4. Above water-supply intakes (also measure or estimate diversion)
5. Above sewage disposal or sewer outfalls (also estimate effluent)
6. Above, at and below towns or cities (at villages or boroughs)
7. At county boundaries or state boundaries
8. Below existing or proposed dam sites (or good potential sites)
9. At major changes in topography (water gaps, fall line, foothills)
10. At major geologic boundaries or soil type boundaries
11. Above and below large well fields adjacent to stream
12. Below lakes and large ponds
13. Above and below swamps
14. At the "treeline" in mountainous regions
15. Below head of perrennial flow (or source if spring)
16. Wherever underflow is believed to begin or cease
17. Every 5 miles if no other criterion governs (in New Jersey)

RELATED RESEARCH

It is desirable to have other parties measure the altitude of the water table at representative locations throughout the basin for later correlative studies. Streamflow during a low-flow period represents the outflow from the shallow ground-water aquifers, except as modified by diversions, storage or other type of regulation. Inasmuch as these modifying factors are measured or estimated in detail in the course of river-system-gaging, it is obvious that such data are invaluable for comprehensive study of ground-water hydrology. For example, areas of extensive glacial deposits containing large quantities of stored ground water may be located in the midst of so-called "hard rock country", where yields from wells are generally very low. Any reaches of streams that gain or lose much water from or to the ground-water reservoir are identified geographically and quantitatively. Furthermore, the chemical analyses of water samples from various parts of the basin may provide additional clues for study of the ground-water aquifers.

There are feedback advantages to the gaging station network. The New Jersey district recently discovered that at two gaging stations leakage or underflow was by-passing the measuring weir and reappearing in the channel a short distance downstream. River-system-gaging reveals this sort of situation quickly if a significant quantity of water is involved. In quite the reverse direction, one gaging station, where the minimum flow seemed unreasonably high for such a small drainage area, was found to be measuring the yield correctly; it just happened to be located below a reach of channel where ground-water outflow was concentrated.

Another interesting facet of river-system-gaging arose in appraising the effects of a large swamp on streamflow. Measurements of inflow around the perimeter of a 20-square-mile swamp added up to more than the outflow during dry, hot weather. This was even more significant because an extensive groundwater investigation in the area showed that there was additional upward flow into the swamp of some 35,000 gallons per day per square mile from the underlying artesian aquifer. This added to the measured surface inflow indicated evapotranspiration was consuming about one-fourth of all water entering the swamp in dry, hot weather. This is contrary to the popular belief that swamps store water which is released during dry weather and thus help maintain flow downstream.

Gordon Ayer reported to this conference in 1959 on results of research as to the effects of reforestation on streamflow.[7/] That project showed that total yield decreased somewhat as tree growth increased but that winter peak discharges were reduced significantly also. Another research project of interest to hydrologists in this region was recently described by Wiitala.[8/] In a controlled experiment he found that urbanization, especially paved areas and storm sewers, materially reduced the concentration time between peak rainfall and peak runoff. Urbanization also increased the magnitude of the peak discharge for that small area by three times over the peak rate that would have occurred if the area were still in pasture and woods.

The above projects are only a few examples of how research adds to our knowledge and hydrologic know-how. It is thus becoming possible to predict with some assurance what the consequences will be if forests or swamps are replaced with residential or industrial developments. However, precise quantitative values must await completion of broader studies than these isolated pilot projects.

PUBLICATIONS

Even precise values will not suffice, however, if that knowledge is locked up in files or published only in highly learned treatises. The results of such data collection and research must be condensed and interpreted in technical journals enjoying a wide circulation among engineers and scientists. And finally the same information should be re-written in simple language and short reports that would be useful in the schools and to busy executives and public officials. These audiences need to know the overall picture but would be confused and disgruntled by the more complex and detailed accounts published for the engineers and scientists.

SUMMARY

In planning an advanced stream-gaging program, the short and long range goals should be decided first. If an adequate network of streamflow stations has not been established yet, this should receive top priority as the records from these stations, along with precipitation records, furnish the basic foundation for all hydrologic study, research, and interpretation. The network should, for efficiency and economy, include some permanent gaging stations and a larger number of temporary stations. In addition, a large number of partial-record stations will supply very useful data for a relatively small cost.

River-system-gaging is recommended as an extension and refinement of the network for data collection. It is believed that much better understanding of the hydrology of a river basin can be obtained in this way. Such research is the key to complete understanding of the many hydrologic factors involved and the interplay between their individual effects. It is essential that such knowledge be gained and disseminated effectively, not only to scientists but also to practicing engineers, public officials and the public at large. Then it may be hoped that the technical, social and political problems involved in the control and conservation of the water resources can be understood as a basis for wise decisions.

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