locks, and especially if funds are not sufficient for any other more radical improvement, resort is usually had to this kind of work. After a general scheme has been adopted work can be carried on at the difficult places first and in this way the most urgent needs of navigation met in order of importance.

Contraction works leave the greater part of the river open for boats, thus avoiding the delays at locks, are generally moderate in cost, can be changed if not entirely successful upon the first trial, may be applied gradually, do not flood the banks nor interfere much with high water flow, and ordinarily indicate the channel to pilots at low water. On the other hand, they require careful study for correct location, are not invariably successful, require considerable maintenance, and are usually limited in effect to a very few feet. They are not adapted to rivers of small discharge and steep slope.

Following European practice, the efforts to obtain 6 ft. navigation on the Ohio River above Cincinnati were directed during the early '80s toward improvement by dikes and training walls, of which many were built at the various shoals. In plan they left the bank in a long curve and followed down stream parallel to the channel, contracting the waterway without protecting the river bed. They were built to a height of 4 ft. above low water and their completion caused a disturbance in the equilibrium therefore existing and was usually followed by a local increase of depths, sometimes at the expense of decreased depths on bars lower down stream where the dislodged material was occasionally brought to rest. This method was only partly successful in the upper portions where the low water discharge was small and shoals frequent. When the 6-ft. project was abandoned and the 9-ft. project adopted for this river, the more radical method of locks and movable dams was selected and the use of training walls abandoned as insufficient.

Dredging in rivers, on the other hand, is immediate in its effect, the expenditure is applied directly to the seat of the trouble, and it is suitable for any type of stream. Dredged channels are usually not difficult to plan and their excavation is seldom accompanied by special engineering difficulties. When well located they are often fairly permanent. If the shoal is caused by a deposit of sediment it will sometimes reform, unless prevented by contraction works so designed as to remove the causes of the original deposit. On the Mississippi redredging each year is still necessary on some shoals, but in hard river beds, elsewhere the channels are often reasonably permanent. It is frequently the practice to use the excavated material in constructing dikes or training walls for a compensating contraction of the river in the neighborhood of the dredged cuts wherever the material is suitable, as is done on the lower Tennessee with good results.

If either dredging or contraction should be followed in river improvement to the exclusion of the other a considerable advantage would be lost, for it is by the combination of these two methods that the best open channels have been obtained in river work.

Regulation by spurs, sills and training walls, supplemented by dredging, merges without any sharp dividing line into dredging supplemented by contraction works, and the predominance of one method over the other will depend invariably on the character of the stream and the results to be achieved.

As a type of work where the contraction feature is the more predominant, the upper Tennessee is a fair example. There the present project is to obtain a 3-ft. depth at low water by open channel work. The methods followed to-day represent the outcome of many years' experience with dikes, bank protection, spurs and channel excavation and will be briefly described. The river has a normal width of about 600 ft., a discharge of about 2,500 second feet at low water, and 395,000 second feet at extreme high water. The bottom on nearly all shoals is either rock or hard gravel overlying rock at varying depths. The variation in bed and banks is so small from year to year that it may be justly described as of "fixed regimen."

The preliminary step is always a careful detailed survey showing the depths, nature of the bottom, low-water slope, and velocities at various places. A study of the physics of the locality is made and the action of the currents at varying stages observed.

The main steps in the work are then as follows:

First, the secondary channels back of islands are usually closed and the best location for the navigation channel selected. This location is almost invariably along one bank, the reasons for which are numerous, the following being the principal ones. It is more easily navigated, especially at night, more easily found by pilots, and more easily maintained, as it usually follows the convex bank where the tendency to re-fill is least. It is cheaper to construct, as the bank can be protected at less cost than a dike can be built; quicker, as the first cut of the dredge can be placed on the bank without using scows or barges for removing the excavated material; and better, as the channel can be straightened if needed and the minor irregularities in the bank corrected. Furthermore, spurs or training walls on both banks on opposite sides to contract the channel have been found difficult to navigate at intermediate stages of the river and often dangerous from the "draw" over them when submerged.

Second, the normal profile low-water width is calculated by the usual formulas involving the width, depth and character of bed, the discharge and slope of the river, and when obtained, is checked with actual conditions in normal reaches nearby. Formulas are never entirely reliable as no mathematical expression is equally applicable to the many varying cases met with, but they serve as a guide and when compared with the natural conditions are often useful.

Third, a combined system of bank protection, spurs and training walls, and sometimes sills when needed, are applied, so arranged as to hold up the water surface after the excavation is made, and so designed as to smooth out the inequalities in the low-water slope and distribute the fall over a longer stretch of river than before in order to reduce the extreme velocities.

Fourth, the bottom is drilled and blasted, if necessary, the material is dredged out and placed in the dikes, and after completion the shoal is re-surveyed to see whether further changes are necessary in adapting theory to the problem. Gages are placed before commencement along the site of the shoals, at the head and foot, and about a half mile above and a similar distance below, to ascertain the effect of the dikes. These gages are read daily. When finished, a survey of the work is made and the new slopes and velocities plotted. It sometimes happens that this survey will indicate that some dikes must be prolonged, or the channel narrowed, or perhaps a dike lowered in height to obtain the best results.

A very satisfactory example of this kind of work on the Tennessee River is at Little River Shoals. The maximum slope was originally 9.5 ft. per mile at low water and is now about 5.3 ft. The low water discharge is about 2,500 cu. ft. per second and high water discharge 395,000 cu. ft. per second. The maximum velocity at low water was over 8 ft. per second, and this has been so reduced that "warping" in passing up is no longer necessary.

On this work the rock excavation cost $1.92 per cu. yd., made up of drilling and blasting at $1.71 per cu. yd. and