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**“The Regulation of Rivers and Waterways, with a view
to the Prevention of Floods.”**

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THERE is such an infinite variety in the characteristic features of each waterway, as regards the configuration and geological structure of the country it permeates,—whether its course lie in the interior of some great continent, and it empties itself into some other river, or into an arm of the sea, more or less affected by the ebb and flow of the tide,—and also as to the extent and nature of the floods and their effect, that an exhaustive description of the regulating works applicable to each case would fill a folio volume. This memoir will therefore be limited to a brief general summary of the first principles requisite to the successful regulation of intractable rivers.

I.—REGULATION OF THE NON-TIDAL PORTION OF RIVERS.

In every case, first of all the upper course of the river must be dealt with separately, and then the lower portion of it, together with its mouth, whether it empties itself into an estuary or into the open sea.

From long experience it has been ascertained that every river or stream, following its natural course through wide tracts of level country, invariably, if the banks consist of deposits of earth or gravel, attacks them, the lighter particles being carried away, the heavier being deposited in the bed of the stream, so that in course of time its width increases while its depth decreases, and at the same time islands, sand-banks, bends, creeks and by-channels are formed.

In rivers thus left to nature the fall, mean velocity, and force of the current are continually decreasing while the river-bed is rising; this naturally raises the general water-level relatively to the adjoining country, and exposes it to frequent inundation, the effects of which are disastrous floods and the formation of innu-

merable branches and by-channels which intersect the whole country, flooding and swamping it at every rise of the river, and rendering it in time unfit for habitation by either man or beast. Instances of the kind are at the present time to be met with in many parts of the world, notably in Asia, Africa, and America.

In order to deal effectually with such cases, namely, to abate the floods, and to prevent the disasters accompanying them, as well as the ultimate formation of trackless swamps, the following procedure is recommended:—

(1.) A new channel following the course of the valley should be carefully laid down by the superintending engineer, either in a direct line or with easy bends, and when excavated, the entire body of water should be admitted into this new channel, the old bed and all by-channels being filled up.

(2.) Having carefully determined—

(a) The discharge per second at low, mean, and high water-level of a cross-section of the river, either immediately above or immediately below the portion to be regulated, and

(b) The increased fall which the new channel will afford; then the sectional area of the new bed must be fixed, according to approved hydraulic formulas, so as to allow of the passage of either an ordinary or an extraordinary volume of water.

(3.) The water having been admitted, the next thing is to protect the banks by random rubble or by stone pitching in order to prevent the action of the current injuring them, or forming bends or creeks.

(4.) After the completion of the above, the old river-bed and by-channels should be filled up, the land thus reclaimed should by degrees be brought under cultivation; in the same manner the marshy tracts exposed hitherto to inundation, and fertilised by the deposit therefrom, should be raised by a coating of rich soil.

(5.) If exceptionally high floods still overflow the banks and inflict loss and damage to the freshly cultivated valley, dikes at suitable distances apart will be necessary to confine such floods, and enable them to flow off gradually without causing damage.

From forty-eight years' observation and experience of extensive works undertaken for the improvement of rivers, the Author can confidently affirm that by careful attention to the points above recommended, even the most tortuous rivers and the swampiest valleys have, generally within a few years, but in some cases only after many years, yielded the most satisfactory results, as for instance—

(a) The increase of fall due to the more uniform section and

more direct course, and the concentration and confinement of the stream within a single channel provided with firm banks, considerably increases the force and velocity of the current, which tend to deepen the channel, and to carry away the material thus scoured out as well as that brought down from above.

(b) By lowering the bed of the river, in some cases to the extent of from 3 to 6 feet, the general water-level, both of the river and of the ground springs in the neighbourhood, is proportionately lowered, so that the adjoining country is less liable to inundation, and the swamps are more easily drained and brought under cultivation.

(c) The velocity being accelerated in the new channel, as shown above (a), floods pass off more rapidly and do not rise so high, consequently the low country is seldom or ever under water, or at any rate not to the same extent as before. If, however, these lesser and lower floods are to be entirely prevented, dikes parallel to the course of the river must be added.

(d) In rivers exposed to the action of frost, floating ice is apt to accumulate in the unregulated portions of its course, especially at sharp bends, and on shallows and sand-banks, occasionally to such an extent as entirely to obstruct the flow of the stream, and to raise the water in the river to such a height that it overflows the banks, inundates the neighbouring country, and spreads ruin far and wide.

When once a river has been regulated this cannot take place, as there would then be nothing to hinder the free passage of floating ice, and should a temporary stoppage occur, the concentrated force of the current would soon overcome every obstacle, by raising the blocks, and bearing them away without causing any flood.

(e) It is a matter of general experience that even in a deep river following a winding course and dividing into numerous branches, navigation is often obstructed to such an extent that the river becomes all but impassable, yet when the same river has been regulated, a direct channel is provided, facilitating traffic and commerce, and increasing the prosperity of the country already improved by drainage and cultivation.

(f) On the banks of many rivers left to Nature but a scanty population exists, invariably affected and often decimated by epidemics, and generally exhibiting an imperfect physical and mental development. After regulation, and by draining and cultivating the adjoining country, these evils disappear, the inhabitants improve in health, strength and intelligence, the population increases, new villages spring up, and prosperity reigns where

before disease and poverty were rife. The Government earns the hearty thanks of all thus benefited, and is at the same time fully recouped the capital laid out on the works by the increased revenues derived from the improved condition of the country.

Where such an improvement of the waterway has been rationally executed, in accordance with the particular nature and requirements of the locality, most, if not all, of the above advantages have been secured; as may be proved by numerous instances of works of the kind executed years back in France, Germany, Austria, Switzerland, and Italy. Moreover, the fact that the Chambers of Deputies of these states have, during the last few years, repeatedly devoted hundreds of millions of florins to the completion of works already begun, and to new undertakings of the same kind, is a proof that the importance and advantage of such improvements are fully recognised.

As a complete description of even the most important works of this kind would far exceed the limits of a short Paper, the Author must confine himself to a brief review of those successfully accomplished on the Rhine and the Danube (Plate 7).

The Rhine, between Basle and Mannheim, has for centuries followed a tortuous course, abounding in sharp bends and dividing into many branches, through a valley between 5,000 and 6,000 metres broad. Having further repeatedly shifted its course, the whole valley became cut up by old channels; to a considerable extent, too, its natural fall was lost, owing to its sinuous course, and consequently the rate and force of the currents were so much diminished, that deposit accumulated everywhere, raising the bed of the river and mean water-level to such a degree that the adjoining country was little better than a swamp. The bed of the Rhine being thus elevated, and its course so irregular, the flood-water could not flow off rapidly enough, but spread abroad, inundating the neighbourhood, and destroying whole villages and townships.

The riverside communities had in all ages attempted, by dams and other protective works, to abate these evils, but with little success, as, owing to the winding course of the river, the floods confined at one point escaped at another, and took their defences in reverse. This deplorable condition of the Rhine valley continued until the commencement of the present century, when the population, already greatly reduced by poverty and disease, was daily decreasing owing to emigration to America.

Colonel Tulla, of the Engineers, an eminent authority on hydraulics at that time, by repeated and unremitting exertions,

induced the Government in 1817 to undertake a thorough survey of the entire Rhine valley. Upon that survey was based the project for the radical regulation of the Rhine-bed, which was approved and ratified by treaty between the border States of France, Bavaria, and the Grand Duchies of Baden and Hesse, and according to which the regulation of the Rhine was carried out during the years 1819 to 1863.

The work consisted in regulating the course of the river and making it more direct. This necessitated the excavation of twenty-three considerable cuts, which reduced the distance by river between Mannheim and Basle from 252 to 169 kilometres, and increased the fall 30 per cent. Further, the stream was confined to a uniform channel of suitable section, both banks were substantially protected, the old river-bed and all branches were filled in, and the land thus reclaimed was for the most part brought under cultivation.

The above-mentioned regulation of the Rhine may be considered one of the most extensive and interesting undertakings of the kind ever attempted in Europe, the scope of which can scarcely be fully appreciated without reference to the exhaustive description and numerous plans issued by the Public Works Department of the Grand Duchy of Baden at Karlsruhe. By these it is proved that the following advantages have been secured, viz. :—

(a) The river has undeviatingly followed the new course provided for it, has deepened its bed to the extent of two metres in some places, and lowered the mean water-level proportionately. Flood-water also has been passed more quickly.

(b) The general water-level being thus reduced in height, extensive tracts of swampy ground have been laid dry and converted into fertile arable land. Further, more than 20,000 hectares of old river bed, water-holes, and sandbanks have been reclaimed, and brought in a great measure under cultivation; and, lastly, the low-lying tracts are now no longer exposed to inundations.

(c) The sanitary condition of the Rhine-valley has visibly improved, and the general prosperity of the inhabitants materially increased.

(d) According to the concurrent reports of experts, Government officials, and local authorities, the benefits derived from the regulation of the Rhine are so considerable that the capital laid out has been amply repaid. Wherefore, in grateful recognition of the eminent services rendered by Colonel Tulla, the original promoter of the scheme, a statue has been erected in his honour at Maxau on the banks of the river.

In one respect only has the regulation of the river not fulfilled the expectations of its promoters, viz., the extensive sandbanks formed at the confluence of its tributaries have rendered intercommunication with them both difficult and dangerous, because these feeders to the main stream enter it across bars little more than 0·60 or 1·50 metre below low-water level.

Had the hydraulic engineers in 1817 correctly determined the minimum discharge of the Rhine, and at the same time anticipated a probable decrease of the same, they would have diminished the waterway, and thereby considerably reduced the deposit and formation of such sandbanks, so that the channels of communication between the Rhine and its tributaries would have remained more open to navigation.

As a second example of the satisfactory result of the regulation of an important river, the works executed on the Danube, near Vienna, during the years 1869–1881, may be cited. These were described in a Paper communicated to the Austrian Society of Engineers and Architects, and published in their journal for 1880.¹

From the plans illustrating that Paper, it will be seen that the course of the Danube at Vienna was by no means so irregular as that of the Rhine. Owing, however, to three sharp bends in the immediate vicinity of the city, and to the width of the river and numerous shoals, vast masses of ice accumulated, almost every severe winter, causing the suburbs to be flooded, and leading to great damage. Moreover, the navigation was much impeded by shoals and shallows, and was exceedingly dangerous between the narrow bays of the wooden bridges. It was impossible to build masonry bridges, and there were no commodious landing-places, as the only place adapted to the purpose was the long sweep of the river at Florisdorff, some distance from Vienna and on the opposite side.

This state of matters was very injurious both to the health and to the commercial prosperity of the city, yet it was not until many years had been consumed in negotiations between the Government, the Landtag, and the Vienna Municipality, that at length a well-considered project for regulating 23 kilometres of the course of the river, from Nussdorf to Fishamend, was sanctioned and commenced with a capital of 32 million florins. The results of this work, already apparent, are as follows:—

1. Although the cut (6,440 metres in length) between Nussdorf

¹ Minutes of Proceedings Inst. C.E., vol. lxi., p. 335.

and Fishamend was only opened in 1876, and the other works were still incomplete, yet the extraordinary quantity of ice that came down the river during the severe winters of 1876 and 1880, as well as the high floods in August 1880, passed Vienna without causing the slightest damage. It may therefore be taken for certain that these dangers to the city have been effectually removed. It is beyond doubt that had the regulation works not been constructed, the huge banks of ice piled up on both sides of the river a short distance below Vienna, would have spread over the low-lying suburbs, as was the case in 1830, and have caused incalculable damage and loss of life and property.

2. Since the low-lying suburbs have been protected against the floods and ice, and the general water-levels of the country and of the river have been lowered about 0.50 metre, the epidemics formerly so prevalent have all but disappeared, the sanitary condition of the population has improved, and the death-rate has been considerably lowered.

3. The river is now 1,890 metres nearer Vienna, and in order to extend the city in that direction a site for a new suburb has been supplied, by filling up the old river-bed, &c., equal to 267 hectares, available for building purposes, after deducting the space to be occupied by projected streets, squares, and gardens.

By diverting the river it has also been possible to remove the old pile-bridges and to replace them by five handsome stone structures, two being for ordinary and three for railway traffic, the details of which are given in the report issued on the occasion of the public opening of the new channel for navigation on the 30th May, 1876.

The course of the river at present affords a navigable channel of a uniform section and easy bends, with a depth of 3 metres at the lowest water-level, so that the navigation is never interrupted.

Three extensive sandbanks have been formed on each side of the river, but offer no obstacle to navigation, as they are everywhere at least 0.60 to 1 metre below the lowest water-level, and they do not extend across the river; this is attributable to the fact that, profiting by experience gained on the Rhine, the width originally determined on, viz., 1,000 feet, was reduced to 900 feet.

5. Along the right bank of the new channel, besides public landing stages, ten quays 1,067 metres long have been constructed, and 13,276 metres of frontage secured, on which numerous warehouses have been built. These have been put into direct communication with all the railway stations in Vienna by the new line along the banks of the Danube, so that all goods arriving at or

leaving Vienna may be transferred from the shipping to the railway, or *vice versâ*, with the greatest facility, expedition, and economy. A roomy winter harbour is also provided for unloading the river craft during floods and during the breaking up of the ice.

In consequence of the above improvements the traffic and commerce on the Danube has quadrupled since the river has been regulated. It is also evident that all the results anticipated have been fully realised, and so many substantial benefits, both to the city and to the country, generally secured, that the immense capital of 32 million florins has been well expended and richly repaid. Mr. James Abernethy, Past-President Inst. C. E., greatly contributed to its success by strongly recommending the plan since executed, and assisting in the elaboration of the entire scheme, when summoned to Vienna in 1867.

The manifest advantages secured by the regulation of this portion of the Danube have induced the Government, Landtag, and Municipality to authorise forthwith the regulation of further portions of the river, namely, from the confluence of the Isper to Nussdorf, and from Fishamend to Theben, on the Hungarian frontier, a length of 157 kilometres, at an estimated cost of 24 million florins.

The next section, from Pressburg to Gönyö, 80 kilometres in length (Plate 7), is quite as irregular as the course of the Rhine between Basle and Mannheim was before 1817. Yet the Hungarians object to its regulation because they are jealous of any increase of traffic between the lower Danube and Vienna, and are anxious to attract it to Budapest. But lately the Hungarian Government has discovered, that the devastation caused to the adjoining country, by floods in this unregulated portion of the river, is on the increase, and that the present difficult navigation has not so much affected Vienna as their own export trade to the westward. It has therefore determined to proceed with the regulation of that portion of the Danube between Pressburg and Gönyö within their jurisdiction, at an estimated cost of about 20 million florins.

Advantage may be taken of this opportunity to refer briefly to the circumstances which prevented the regulation of the Theiss in Hungary being productive of any permanent improvement, and in fact rendered it a complete failure. It is beyond a doubt that the depressed Hungarian basin was at one time occupied by a vast inland sea, which gradually drained away after the Danube had forced a passage through the mountains between Moldova and Orsova.

The river Theiss receives the entire drainage from the Carpathian mountains, and after a most tortuous course through the level plains of the above basin, delivers it into the Danube. Throughout its whole course below Szolnok it falls at the rate of only 1 in 46,000, and latterly of 1 in 60,000; whereas in its upper course, between Tokay and Csáp, the fall is at the rate of 1 in 19,000 to 1 in 5,200. The wealthy landowners on this upper portion of the river have protected their own property from the effects of floods by providing a direct course for the Theiss, and confining it to that course by a continuous system of dikes. The natural fall has therefore been increased, and consequently it now bursts with redoubled force into the lower reaches, where the fall is very slight. Besides, in the lower portion of the river, little has been done to provide a more direct channel, and the dikes thrown up on either side have been constructed in such a haphazard manner, that in some places they are actually at right angles to the course of the river, besides being at very unequal distances apart ranging from 400 to 1,400 metres.

Lastly, no increase to the cross-section of the channel has been attempted, though repeatedly recommended by the most eminent hydraulic engineers; nothing has been done to improve the course of the river Maros, which flows into the Theiss at right angles to the latter, nor has its junction with the Danube been regulated. It is but natural that the works undertaken on the Theiss, and executed in direct opposition to the first principle of hydraulics, should have proved most unsatisfactory; that floods should have been intensified, the dikes breached, and wide fertile tracts inundated and laid waste—a calamity that, on the 12th March, 1879, befel the populous commercial city of Szegedin.

These unsatisfactory results should in no way shake confidence in the undeniable and proved success of many rationally executed works of the kind in Europe and elsewhere, but rather serve as an example and a warning that improvements conducted regardless of true scientific principles can only end in that way.

The depth of water in almost every river having sensibly decreased within the last ten years, to the serious obstruction of navigation, whereas at some seasons the floods have risen even higher than before, some German engineers have given it as their opinion that this is owing to the regulation of rivers, as they affirm that the ordinary flow passes off more rapidly when confined to a channel of a regular section and direct course; for the same reason the floods also descend more quickly from the high ground and rise to a greater height. Arguing from the above hypothesis,

these engineers maintain that the execution of regulating works is disadvantageous, and propose instead the construction of capacious reservoirs to impound the surplus rainfall, so as to prevent floods and at the same time to regulate and maintain an equable flow of water at all seasons.

The Author cannot assent to this theory. In all the Papers published by him from 1873 until 1879 he has clearly shown that during the last ten years the supply of water derived from natural springs has perceptibly decreased, and consequently the level in rivers, &c., has been lowered. This would have been still further the case had the rivers remained unregulated, because the same quantity of water spread over a wide irregular bed, and distributed in many branches, would expose a far larger surface to the atmosphere, and consequently more water would be lost by evaporation.

Floods at the present day occur in the regulated channels, rising even higher than formerly, in spite of the rapid overflow, and for this reason, that in consequence of the clearance of forests, especially on mountain tracts, rain-storms are more frequent; further, because the reduced total rainfall penetrates nowadays less into the ground, and flows off from the treeless slopes of the mountains and country, now intersected by numerous ditches and drains, into the rivers much more rapidly and in greater quantities, which accounts for these heavy floods.

The extraordinary advantages of constructing reservoirs in the drainage area of rivers was recognised by the Chinese four thousand three hundred years ago, and even at that time many reservoirs several square miles in extent were constructed in connection with the regulation of their larger rivers.

In the present day, when every square yard of ground, even in mountainous districts, is private property, and obtainable only at almost prohibitive prices, the construction of huge reservoirs in the drainage area of rivers would be both difficult and expensive. Besides, such reservoirs could be of little or no use in connection with an unregulated river, consequently its regulation would in the end be obligatory.

Latterly, numerous ideas and projects for regulating and making navigable natural river courses, and at the same time preventing floods, have been propounded. But regarding them as impracticable, and as unlikely to lead to any favourable results, it is needless to enter into a discussion of their merits.

II.—REGULATION OF RIVERS EMPTYING INTO THE SEA, OR INTO AN ARM OF THE SEA.

The irregular course of rivers flowing into the sea is due principally to the facts, that in the lower part of their course the inclination of the bed is inconsiderable, and that frequently bars are formed at the mouth by the joint action of the river and the sea. The bars also prevent the egress of the land water, driving it back and flooding the adjoining country, until the ebb of the tide permits the river to flow again and find its way into the sea, by the numerous channels it has forced through the delta at its mouth.

The regulation of rivers flowing into the sea is a much more difficult and a more costly undertaking than that hitherto treated of; for the volume of water to be dealt with is greater, and the loose and yielding nature of the deposit forming the banks and bed of the river, as well as the violence of the storms and force of the waves, render it necessary that the protection of the banks and all structures should have solid foundations and be executed in the most substantial manner.

The ordinary works necessary to the perfect regulation of such a river consist of—

(1) Rendering the course as nearly straight as possible in order to increase the fall.

(2) Enclosing the river near its outfall by means of dikes, and continuing the same beyond the bar and as far out to sea as possible, that the force of the current may be sufficient to carry the sand and mud to such a depth that the action of the sea may carry it away and prevent the formation of a bar at the mouth.

If the adjoining country is to be effectually protected from inundation produced by the action of the tide, it will be necessary on either bank, beyond the limit reached by the tide, to construct dikes at such distances and in such a manner that at ebb tide the force of the river may be sufficient to carry out to sea the silt, &c., deposited during the flow of the tide; when the river is thus confined, then the low country beyond the dikes may be drained and brought under cultivation.

It is not proposed to discuss the works executed for regulating rivers falling into the sea. It may suffice to mention the celebrated works at the Sulina mouth of the Danube, those at present in course of completion at the mouth of the Mississippi; and, lastly,

the successful drainage and cultivation of the deadly swamps of Tuscany and the lowlands of Holland, lying 5 feet below mean sea-level.

The vast experience gained in Europe in works of this description justifies the opinion that the science of hydraulics has, thanks to the observations carefully recorded for many years, arrived at such perfection that every practical hydraulic engineer is in a position to project and execute works calculated to rectify a bad waterway, to drain a swampy tract, and to prevent the recurrence of floods and their dreadful consequences.

Lastly, a few remarks may be permitted upon the Papers by Mr. Wheeler and Mr. Jacob on the Conservancy of Rivers, dealing respectively with the Eastern Midland District of England, and with the Valley of the Irwell.¹ From these communications it would appear that the irregularities in the course of the four rivers draining the Eastern Midland counties, and of the Irwell, were not due so much to the configuration of the country or to natural causes, but

(1) Chiefly to the independent way in which, on their own section, each proprietor carried out the improvements he judged best, without any regard to the very first principles of hydraulics, and utterly regardless of their effect on the course of the river above or below him.

(2) To the fact that the weirs, sluices, and other works, were built too high and too narrow, thus facilitating the formation of sandbanks and the silting up of the river-bed, and so hemming in the ordinary freshets as to force the water over the banks and flood the adjoining country.

(3) The scouring and deepening the bed of the river by the action of the tide was rendered impossible by the numerous weirs, sluices, and other obstructions connected with the supply of water of the mills, as well as by the bad management of the same, so that not unfrequently the floods were permitted to lie on the land for weeks together, rendering it little better than a swamp.

According to Mr. Jacob, all the slag, refuse, and even the earth excavated for the foundations of smelting furnaces, factories, and dwelling-houses, in the immediate vicinity of the Irwell, were shot into the river or on to its banks, to be swept away by floods into its bed; so that it is scarcely to be wondered at, that

¹ Minutes of Proceedings Inst. C.E., vol. lxvii., pp. 201 and 233.

rivers so treated should at length become so obstructed as to cause frequent and destructive floods.

The evils thus produced by ill-designed structures and by the bad management of those in charge of them were further augmented by two circumstances:—

(1) That the bar at the mouth of the river raised the ordinary water-level, and dammed up and forced back the flood waters, so that the country around was continually exposed to inundation.

(2) In consequence of improved cultivation and better drainage the rainfall in the upper basin of the river flowed off in greater quantities and more rapidly than formerly, while the section of waterway, and the weirs and sluices on it, had not been proportionately increased; this raised the height of the floods and increased the area subject to inundation.

From the minute particulars given by Messrs. Wheeler and Jacob, the Author feels himself in a position to express a general agreement with the suggestions made by them for regulating the rivers and remedying the evils complained of, because they evidently coincide with the principles applied with success to many works of a similar kind in Europe and elsewhere. On the strength of long practical experience in this branch of the profession, he would beg to be allowed to make the following remarks:—

(a) In the first place, the discharge per second at important points on each of these five rivers during high floods should be carefully ascertained, so that a suitable cross-section for the channel and for the sluices might be fixed.

(b) The masonry weirs across the bed of the rivers should undoubtedly be removed, as at present they tend to augment the floods and to facilitate the silting up of the bed, and if allowed to remain, would render a complete regulation of the river either impossible or nearly useless.

(c) The sills and floors of all existing sluices and locks, as well as of those to be constructed in place of the present weirs across the bed of the river, should be laid several feet below the present river-bed, in order that, after the regulation, the anticipated lowering of it may meet with no obstacles.

If a thorough regulation and removal of the present ill-designed regulating works be carried out, it is certain that the serious floods complained of will cease, the inundation of the adjoining land disappear, the greater portion of these rivers be rendered navigable, agriculture flourish, and the health and well-being of the population improve, the mortality decrease, and the capital expended thereon give an abundant return.

From the concluding remarks of the above gentlemen the Author gathers that none of the improvements advocated by them can be put in hand, until Parliament has passed an Act for the better regulation and control of all works erected by private enterprise, and for a due inspection of the same. The Institution of Civil Engineers might, therefore, render immense service to the inhabitants of many river-basins were it to exert its influence in promoting such an Act of Parliament, and aiding to the best of its ability river improvements of this description.

Several maps accompanied the Paper, from which Plate 7 has been engraved.

THE RHINE BETWEEN WINTERSDORF AND ILLINGEN IN 1838.

THE RHINE BETWEEN WINTERSDORF AND ILLINGEN IN 1852.

THE DANUBE BETWEEN PRESSBURG AND GÖNYÖ IN 1860.