BROOKS ON THE IMPROVEMENT OF RIVERS

TREATISE

ON THE

IMPROVEMENT OF THE NAVIGATION

OF

RIVERS:

WITH A

NEW THEORY ON THE CAUSE OF THE EXISTENCE

OF BARS.

BY

WILLIAM ALEXANDER BROOKS,

M. INST. C.E.

"Nos erreurs sont, en cette matière, d'une toute autre conséquence que dans les objets de goût, de luxe, ou d'agrément; parceque toujours il en résulte, ou un dommage réel, ou la perte de quelque avantage précieux."—DU BUAT.

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CHAPTER I.

ON THE BARS OF RIVERS.

THE subject of this chapter is one of the very highest importance, whether it be considered in relation to national objects, or to science.

This has been so much felt in past ages, as well as in our own times, that many works of great magnitude have been undertaken for the purpose of obviating or removing the impediments to navigation, arising from the presence of bars. Many theories have been advanced to account for the formation of bars, amongst which I shall first notice that propounded by Major Rennel, in a note to his translation of Herodotus, which, moreover, describes in clear and general terms, the appearance usually presented by them.

" All rivers," says Major Rennel, " preserve to a certain extent of space, which is proportioned to the harbours; and wherever there is a backwater, or what is termed a scouring power, in operation, there a bar exists; and it is an invariable fact, that whenever attempts have been made to remove bars by increasing the velocity of the natural currents into the ocean, there the bars have also increased in proportion. To these consequences no exception is to be found in the whole globe, and in many cases, harbours have, from the causes alluded to, been blocked up and lost! But if the current or tide be by artificial means conducted into the ocean so as to join the sea tide at an acute angle, no conflicting action can arise, and then no bar will accumulate, but whatever silt or other matter be in that case held in suspension by the tides or currents will be carried away from the harbour's mouth in the direction of the tidal water of the ocean[1]."

A fifth assigned cause is an imagined insufficiency of backwater.

Commencing with the theory given by the talented translator of Herodotus, I venture to submit that it is insufficient to account for the formation of bars, because the operations described as producing the latter, take place in all rivers in a greater or less degree, and in those which, although their waters are most abundantly loaded with sand or mud, are nevertheless free from the presence of bars; and here it

[1] Nautical Magazine, p. 487.

may be observed, that deposits on either side of the channel of a river do not come under the denomination of bars; such for example as the sands at the mouth of the river Thames, lying between the Nore and the sunk lights.

The theory that bars are caused by the action of waves is also insufficient, because those impediments to navigation are not only found in the most sheltered situations, or where they are comparatively little exposed to the action of waves; but many rivers whose waters are loaded with silt, and whose embouchures are open to the most furious seas, are nevertheless free from any deposit forming bars.

The action of waves in piling up detritus can only take place where local causes exist, such as a shelter from, or a check to the onward impulse to the sand or shingle produced by the action of the prevailing gales; the tendency of which latter is, as stated by Professor Playfair, to carry all detritus seaward; whether that detritus be produced by the action of the elements upon the cliffs, or brought down by the river waters; and this because of the preponderating effect arising from the slope, or declination of the shore towards the depths of the sea.

That the casual direction of the lower reach, or position of the mouth of a river, cannot be truly assigned as the cause of the existence of bars, is easily proved by observations on rivers subject to great variation at their entrance, the bar being always found to exist quite independent of the direction of the discharge into the sea. This fact at once refutes the third and fourth theories which have been noticed above.

The fifth theory, a supposed insufficiency of back-water, can offer no cause for the formation of a bar; but solely for a general deficiency of sectional area, or limitation to the dimensions of the channel. The mighty waters of the Orinoco, and Mississippi, are obstructed by bars, having on them less depth of water than is found at the mouths of rivers utterly insignificant in comparison to the former, as regards the volume of water they discharge.

The consideration of the cause of the formation of bars has engrossed much of the attention of the Italian and French engineers, and the subject has been fully entered into by Colonel Emy of the Engineers, ex-director of the fortifications of Rochelle and Bayonne, in his interesting treatise on the "Movement of Waves, and of Hydraulic Works;" in which the Colonel has started an entirely new and ingenious theory to account for the existence of bars, which cannot without injustice to him be referred to, except by large extracts descriptive of his views.

In section 94, Colonel Emy thus introduces the subject. "A bar is a bank of sand which obstructs the embouchure of a river. The cause to which has been attributed the formation of bars is that a stream, flowing on a horizontal bed, on its approach to the sea, spreads its surface and diminishes in depth, so that on its meeting with the current of the flood, or even solely with the mass of the water of the sea, a stagnation is caused, by which the sands are deposited, whether brought by the river or by the flood tide.

" It is easy to comprehend that this explanation is not satisfactory, for the repose supposed to take place at the meeting of the currents cannot exist. In the Mediterranean, the current of the flood is never opposed to any stream. In the ocean, one of the two currents overcomes alternately the other.

" If the assumed repose resulted from the equilibrium of the two currents, or solely from the resistance of the sea to the current of the river, all rivers would have bars, and they would certainly be at a greater distance than where we find them, since the current of the river always extends far into the sea.

" The action of the ground waves, "*flots de fond*," is the true cause of the phenomenon of the bar. Those bottom waves which have traversed the shore current, and which present themselves directly to the mouth of a river, enter, or are stopped, according to the manner in which the bed of the river is connected with that of the sea. If the bed of the river be a continuation of the bottom of the sea, or if it be united with it by an extremely easy inclined plane, or by a gentle curvilineal figure, the ground waves penetrate into the river. In tempests they carry with them sand, which is deposited in banks of little height, because they are able to spread, and all that is raised above a certain level, is scoured out again by the action of the current of the river during calm weather. In great tides, the ground waves meeting with nothing opposed to their progress, even on the banks of sand which have not steep sides, produce, more or less, before them in the river the phenomenon of the bore. It is thus that banks of sand are formed at the mouth of the Gironde, and that the bore shows itself higher up in the Dordogne. But if an irregularity of the bottom, such as an acclivity, or a steep slope, exist at the mouth, the ground waves rise in encountering the obstacle, and being no longer able to continue their course under the tidal stream, because their movement ceases to be in harmony with the undulation, they are met and dispersed by the current of the river; and during the moment of repose that their waters find in mixing with those of the river, the sand which they held is precipitated, and quickly thrown above the declivity, by the succeeding ground waves, which repeat the operation.

"This sand forms the bar, which increases rapidly in stormy weather, because at that time the ground waves bring to it an abundance of materials, and deposit them as on a flat shore.

"The bar increases quickly, and would even rise above the level of high water, if the current of the backwater and that of the ebb united had not sufficient force to repulse a portion.

"The sea side slope of the bar, being kept up rather steep by the action of the ground waves, produces in regard to them the same effect as the sides of sand banks, or elevations of the bed of the ocean; it causes them to break on the surface of the water.

"A great number of rivers have bars which render their entrances difficult and dangerous; one of the most remarkable, and which has engaged the attention of many engineers, is that of the Adour.

"It appears to be principally formed from the siliceous debris of the shores of Spain and Portugal, brought along by shore currents, which the ground waves drive afterwards to the shore of the Landes, where they furnish by their trituration the materials of the sand hills.

"A portion of these sands forms the bar of the Adour, the height of which varies between the level of high and low water, the overplus being repulsed by the current of the backwater, and by that of the ebb during calms, when there cannot exist but very weak ground waves, which have not the power to throw up as much sand as these currents are able to drive out to sea. We observe in fact, that the extent of the bar is diminished in long calms, and that it augments rapidly during storms.

" At high water, and when there are waves, the position and figure of the bar is discerned by the form which the ground waves impress upon those of the surface, which become short, and sometimes broken, in passing over.

" In storms, the tumultuous foam from the breaking of the waves marks out the bar; but in calms, as there are then no surface waves, and consequently no sensible ground waves, nothing indicates at high water the place of danger."

The reader will perceive from the foregoing extracts, that Colonel Emy attributes the formation of bars, to what he calls "ground waves," "*les flots de fond.*" A phenomenon believed by him to exist, but of which a description in his own words is requisite, in order to place the gallant officer's theory fairly before the public.

" *Flots de fond.* Behold me arrived at the principal object of my researches, to the description of ground waves, a submarine phenomena which has caused the ruin of a great number of maritime works, which has given to the sea the means to ravage its borders and to destroy cities, which in other situations has augmented portions of continents, has filled up ports, has surrounded them with sands and deposits of clay, and has left in the midst of land, towns whose walls were once lashed by the waves. All these effects have hitherto been attributed to currents of the sea, and to the simple action of waves, but the phenomenon of ground waves is about to resume its rights as a formidable agent of the power of the seas on the globe."

Without the necessity of any horizontal sections to illustrate Colonel Emy's theory, it is sufficient to state, that this assigned theory for the supposed existence of ground waves, *independent of those surface waves which are apparent to all*, is based upon the belief, that wherever the bed of the sea presents an irregularity of surface within the limits of the vibrations of the upper waves, the previous undulatory motion of the lower filaments of the wave is changed to that of a horizontal, or purely progressive one, independent of the undulatory motion of the upper division of the wave, which continues as before.

Thus, supposing the bed of the sea, within the limits of the orbits described by the lower filaments, or strata, of the waves, happens to rise in successive lifts or platforms, such as frequently occur in the stratification of the rocks forming the bed of the sea; the result, according to the theory of Colonel Emy, is, that on the lower portion of the wave striking against the abrupt face of the submarine cliff, which is presented to it, the body of water, in lieu of rising to the surface, and forming breakers, according to my observations, merely surmounts the obstruction, taking a subsequent horizontal, or level course along the surface of the platform, or elevated bed of the sea, and below the superincumbent waves, which continue their undulations towards the shore. On this point he says: "Although the ground waves glide on the bed of the sea, that bed does not occasion any sensible reaction on them; or rather they guarantee the superior undulations from that reaction; so that however great may be the breadth of the platform or elevated bed, provided the ground waves meet with no greater accident, they are only animated with a horizontal movement; *they continue their course under the mass of undulating water, and not only are they not thrown from below upwards*, but they assist in the completion of the undulatory movement of that mass of water, since by their translation they make up for the want of the undulation of that part of the volume of the wave, which is obstructed by the elevation of the bed of the sea.

"When the bed of the sea rises by successive steps of little elevation, the ground waves formed at the lowest stage continue their course; each wave on arriving at the acclivity rises over it by the effect of the pressure of the undulation of the mass on its outer flank, and becomes merged in the ground wave which is formed on that platform; but the ground waves thus produced by the effects of several successive elevations of the bed are of greater volume than those resulting from a single elevation; although the latter be equal to the sum of all the smaller ones; by reason that at every obstruction the ground waves, by their rise upon it, lift the surge of the surface wave, and because these latter, thus lifted up, give place in the same time to the formation of ground waves, which have also a greater relief."

In investigating the correctness of this theory, the inquiry becomes narrowed into the consideration, whether the sudden elevations of the bed of the sea have the effect attributed to them by Colonel Emy? or whether their result is, according to the usually received opinion, that of *the formation of breakers immediately on any portion of the wave meeting violently the vertical face of the obstruction?*

The north-eastern coast of Yorkshire presents in a remarkable degree the geological features which would produce the ground waves according to Colonel Emy's theory; but a residence of several years on its shores, and a close observation of the effects produced by the seas striking against the faces of the rocky shore (the bed of the sea consisting of a succession of platforms of rock, or submarine cliffs), enables me to state, that breakers are formed at the edge of every successive platform; and that those seas which break against the faces of the outermost platforms are much heavier than those which break nearer the shore.

My reason for devoting my attention to this subject, was my desire to ascertain, at what depth in that locality, the waves broke in ordinary and extraordinary gales of wind ; and for this purpose the peculiar configuration of the coast enabled me to take a position in a line with the march of the waves towards the shore; from which I could with a sextant determine the situation of the commencement of the line of broken water; and on laying down the angles thus obtained, I found them always to coincide with one or other of the faces of the rocky platform of the sea, in proportion to the violence of the gale. The surf produced by the opposition of the inner lifts of rock, being also always of small elevation.

This shore would be a gaining one if Colonel Emy's theory could be substantiated, but the reverse is the case; and where the indentations of the coast form bays, there is no diminution of the depth within the latter.

Again, any accumulation which has drifted by the wind beyond the line of high water in calms, is invariably, wherever it is reached by the surf of an on-shore gale, carried out to sea by the back sweep of the returning surge, or by what mariners call "the undertow."

If ground waves were formed, and were capable of producing the accumulation of sand forming bars at the mouth of rivers, which accumulation is according to Colonel Emy's description only reduced by the discharge of the backwater, the same effects ought to be manifested all along the shores on each side of the bar, or embouchure of the river.

So far from this accretion taking place, it will be easy to refer to many bar rivers situated upon coasts upon which no accretion occurs.

The bars of rivers exist quite independent of the line of coast losing or gaining ground.

The example which has been adduced by Colonel Emy, of the bar of the Adour being found to increase in extent during tempestuous weather, and to diminish during long calms, shows that the deposit is really due to the onward or progressive motion of the sand along the shore, which being checked by the piers or jetties, between which the Adour is conducted, lodges under their shelter, and thus is the bank of sand augmented during gales of wind, until it is reduced by the outpourings of the river. The increase of sand is such as would occur between the piers of any harbour unprovided with backwater.

This has been well expressed in the *Nautical Magazine* for February 1838, in a letter signed "Investigator:" the only error in which is, in the extension of the operation to the formation of bars, which are always permanent obstructions. "The sand, or shingle, travels along the shore in the direction of the prevailing winds and currents. A pier built across the beach, stops this shingle till it has filled up the angle of the pier; it then goes on round the end of the pier, part entering the harbour, and the other part, though going on past the opening, shoaling the water in its track, till it reaches the shore on the other side of the pier. This shoaling, or track of the passing shingle, is the bar; and the depth of water upon it is dependent upon the scouring power of the stream which runs over it. The sectional area of the channel at low water over the bar, being necessarily (in such material) proportionate to the stream which every low water makes its passage over it."

There is then at the mouth of the Adour a bar which never can be removed while the river is in its present state; and there is also *an occasional lodgment of sand*, which is capable of being removed by the backwater during calm or moderate weather.

From my own personal examination of bar rivers, I do not find that any material alteration takes place in the depth of their entrances; and certainly during a succession of long calms no increased depth is attained, such as should be produced by Colonel Emy's theory; indeed, according to his views, during long calms all bars should totally disappear; but we know that this is not the case.

Happily, his theory is not correct, for if it were, we should find so great an alteration during the long continuance of on-shore gales of wind, that the mouths of rivers would be totally unserviceable when most required for refuge.

If the pier at the mouth of the Adour, which is next to the side from which the sand or shingle is brought by the surf, had been made convex to the quarter from whence the impulse is derived, or that windward pier had been made concave to the action of the current; the latter, seeking always to escape at a tangent to a curve, would prevent the possibility of any sand lodging in the channel alongside its face.

This latter arrangement would guarantee that no lodgment should ever take place within the piers; the river bar would still exist outside the pier ends; and its removal or amelioration could only be effected by a treatment which will form the subject of succeeding pages.

In conclusion, with reference to Colonel Emy's work, which contains much valuable information, I will only add a few remarks on his section for a sea-wall, which he proposes to be formed curvilineal at bottom; the curve being so arranged, that the bed of the sea, where it meets the base of the wall, shall be tangential to it; and upon the utility of which he thus reasons: "The ground waves being masses of water which roll on the bottom of the sea conducted by the undulations, the best means to destroy their shocks is to present to them a surface which shall turn them at each instant of their direction, so that from the horizontal, which that direction is at first, it shall by little and little, and without any shock, be forced to become vertical."

Is not this effect of a vertical direction, or the conversion of the waves into breakers, produced still more completely by the waves meeting the abrupt faces of the submarine cliffs, to which Colonel Emy assigns a different result; that of the formation of ground waves with a horizontal motion?

CHAPTER II.

ON RIVERS WHICH ARE FREE FROM BARS.

It will generally be found, that whenever a navigable river approximates to the condition of a simple inlet, for the reception of the tide, so far as regards the longitudinal section, presented by its surface at low water, it will either have no bar, or be but lightly obstructed by one; the same may be said of those sea ports, or pier harbours, which, though free from bars in their natural state, are well known to become encumbered by them immediately on the introduction of an artificial scouring power. Resuming the investigation into the state of a river, whose entrance is free from a bar, we shall find, that, from its junction with the ocean, a long line of navigable course exists with an extremely gentle fall, or slope of its surface, at low water; the river is in this case in a proper train, its longitudinal section presenting a succession of inclined planes, becoming more and more gentle, as they approach the ocean; and the lower course of the river, from the slightness of its fall, approximates to the condition of a frith, or deep inlet, of the coast, or to that of one of those large natural or artificial harbours, which, being mere tidal receptacles, wherein the influx and efflux take place in equal times, are necessarily free from bars.

The river, being in this perfect state, as regards the slope of its surface at low water, a consequent attendant upon the latter will be an equal duration, or nearly so, of the period taken up by the flow of the flood tide, with that of the ebb, in the lower reach of the river; by the term flow being understood, the direct upward course of the current of the flood tide, immediately after the true time of low water. Assuming that to the possession of a nearly equal duration of the period of the ebb and flow, in the lower reach of a river, accompanied by an extremely gentle inclination of its surface at low water, is to be attributed the freedom from the incumbrance of a bar, I will now pursue the investigation, into the actual condition of Bar Rivers.

CHAPTER III.

ON BAR RIVERS.

An accurate examination of the state of a bar river will exhibit a great irregularity of its surface at low water; in lieu of the river presenting at that period a longitudinal section of a succession of inclined planes, described in the preceding description of rivers free from bars, as becoming more and more gentle in proportion to their proximity to the ocean, it will be often found that the declination or slope of some of the upper reaches is less than those nearer the ocean; and the fall at low water in the lower reaches of the river is always so great, as to produce a striking difference in the vertical rise of tide, even at a short distance from the sea; and attendant upon this defective state of the section presented by the surface of the river at low water, is a great extension of the duration of the ebb, beyond that of the upward current of the flood tide.

The river being in this irregular state, the process by which the bar is formed may be thus described.

During the period of the first quarter flood, the current, in lieu of being able to take its natural upward course, as in rivers where no bar exists, is opposed, or effectually checked, by the effluent backwater; the declination of the stream in the lower division of the river presenting a head which insures a strong downward current, long after the tide would have been able to maintain an upward course, provided the backwater had had a free discharge. At this period the flood tide, by reason of its greater specific gravity, occupies the lower stratum of the tide-way, and like a wedge endeavours to force its course up the channel, which it is unable to effect, but merely elevates the lighter effluent water, the lower strata of which, being checked by the opposition of the tidal water, yields to the latter the sand or other materials, which it was capable of holding in suspension, previously to its encountering the conflicting action of the flood-tide; and where this takes place the bar is formed.

From the above, we may easily extend the illustration to prove that, while the formation or increase of the bar takes place at this period, or during the first part of the flood-tide, the direct tendency of the whole period of the ebb, when unobstructed by the tidal current, must be to reduce the extent of the bar in all its dimensions.

The same useful effect, in keeping down the bar, must also attend the action of the flood-tide, after it has attained a true run up the channel.

Turning our attention to the state of those rivers, which discharge their waters into tideless seas or fresh water lakes, we shall still be able to trace to the same cause the existence of their bars, viz. to the excess of slope, which their longitudinal sections present near their embouchures: but as here the agency of the tide or counter current does not exist, the deposit which takes place will generally be differently affected from that which forms the bar of a tidal river, which latter does not usually experience that great observable elongation of its course, which takes place in rivers which discharge their waters into tideless seas.

The extension of the course of a tidal river only existing where the latter discharges its waters into a shallow sea or protected bay, the observations on this subject, by Major Rennel, are so clearly expressed, that I cannot do better than give them in the words of their distinguished author.

"It is a circumstance well known to the generality of readers, that rivers which deposit great quantities of matter do also very often separate into two or more branches, previous to their discharge into the sea; thus forming triangular spaces, which the Greeks very aptly called Deltas, from the resemblance they bore to the form of that letter of their alphabet, and also that these Deltas almost invariably encroach on the sea, beyond the general, and it may be supposed, the original line of coast. However the formation of such Deltas, even by rivers of the first magnitude, is by no means universal; on the contrary, some of them terminate in deep inlets or estuaries instead of projecting forms; or, if the expression be allowed, they terminate negatively instead of positively; of this class may be reckoned the great rivers of the Amazons, Plata, and the Orinoco; besides many others, which perhaps bring down an equal quantity of the matter of alluvions with the Nile, Ganges, or any other river, that may form the projecting Delta. This difference appears to be owing to the original conformation of the adjacent coast, and to the depth of the sea beyond it: if the estuarium into which the river discharges itself, and the sea beyond it, are exceedingly deep, the alluvial matter will be lost in the profundity; whilst in a shallower sea, not only the bed of the inlet itself will be filled up, but the matter will form a projecting tract beyond it; and here it may be observed, that the increase of Deltas will almost necessarily be slower in modern, than in ancient times, since the farther the work advances, the deeper the space to be filled up must be.

"It is no less certain, that during the progress of forming by its deposition the low-land which is to constitute the future Delta, the river by its overflowings above also raises such parts of the adjacent countries, as are subject to be overflowed by its waters; and hence it must be conceived that such rivers must gradually raise their beds, since, in order to run at all, they must have a continued declivity the whole way to the sea; so that the very act of extending their course by forming new land to the sea requires a gradual elevation of the ground the whole way from the margin of the sea upwards: thus alluvial countries must continue to rise by slow degrees, whilst the alluvions encroach on the sea, and the rivers themselves continue to overflow and deposit."

By this natural elongation of the course of rivers by the deposit of alluvial matter, a gradual amelioration of the navigation must take place, inasmuch as that elongation is necessarily attended with a more gradual junction with the waters of the sea, or the diminution of the velocity of the current at the point of discharge; we have therefore only to assist the operations of nature by directing the course of the current, and thereby the position of the deposit of the alluvions, to insure that the latter shall act beneficially and not prejudicially to the navigation.

In a tidal river, where a bar exists, and the reduction of the declination of the low water surface cannot be effected, by reason of a long length of rocky bed, too costly to remove, the only means available for its improvement is an artificial elongation of its course, by piers or other works, to bring the mouth of the river within the influence of a stronger current.

Where the declination of a river is great in its lower reaches, the result of any cut near the embouchure of the river, which is not attended by a simultaneous reduction of that declination, must be the increase of the bar. It is however to be observed, that the natural attendant effect of the shortening the course of the current, is the more free discharge of the water and abasement of the level of the surface of the current; and wherever this latter circumstance does not take place, it is solely due to the presence of some geological feature, such as rock or marl, which the current, when unassisted by art, is unable to act upon.

CHAPTER IV.

ON THE BARS WHICH ARE FORMED AT THE MOUTHS OF HARBOURS, OR RIVERS, BY THE USE OF ARTIFICIAL SCOURING.

THE formation of bars to tidal harbours, by the use of scouring reservoirs, is due to the same causes which have been assigned by me as producing them at the mouths of rivers: but designing at a future period to give my views on the construction of harbours, I shall in this treatise confine my observations to the use of artificial scouring powers, or tidal reservoirs, where used with the view of increasing the effect produced by the natural backwater of rivers.

It will be readily perceived, that the formation of a bar at the mouth of a harbour, or river, is due to the same causes which I have ascertained to produce the like results in tidal rivers; viz. to the excess of slope, which the effluent water has given to it, by the mass or reservoir from which it proceeds;

the slope or declination of the scouring current being to be estimated from the level of the surface of the water in the tidal reservoir; hence we find, that however powerful may be the effect of the current in deepening the channel, so long as the stream is confined laterally, its utility is lost immediately on the effluent water being allowed to spread, and the sand or gravel which it carries with it in its confined course is then deposited in a fan-like form; because the artificially heightened current becomes at liberty on every side to subside to the level of the surrounding water.

Hence, we observe that where an artificial scouring power is applied to deepen natural inlets, or harbours, bars are created of which no traces previously existed.

Assuming, therefore, that the volume of the natural backwater is so small as to be inadequate to maintain a sufficient depth in the harbour for the maritime wants of the port, and that the aid of an artificial scouring power be requisite, still the latter should not be made use of, except during that period of the ebb when its effect is to remove seaward the matter held in suspension by the effluent water.

If therefore any portion of the artificial backwater be discharged during still water, or during any period of the flood tide, we may anticipate a rapid deposit, or accumulation on the bar.

In order to secure the utmost useful effect from an artificial scouring power, it is essential that its action be prolonged to a position which is within the range of a strong tidal current, or within the reach of the effect of the prevailing onward impulse by the surf, during on-shore gales.

Where the scouring power terminates *negatively*, if I may use the expression advanced by Major Rennel, or where the effect of the scouring power is unable to extend into a true tidal shore current, it is unreasonable to expect its utmost useful available result.

Thus, supposing the bar produced by a scouring power be situated in a sheltered situation in a bay, there can remain no hope for its improvement until the place of deposit be removed into the true run of the ebb tide.

CHAPTER V.

ON THE REMOVAL OF DETRITUS SEAWARD.

In attempting the amelioration or removal of the bars of rivers, we cannot be said to war against nature; because, the tendency of the waters of rivers is to remove all detritus or alluvium to the depths of the sea; that being the preponderating direction, arising as well from the declination of the bed of the river and the sea shore, as from the volume of the ebbing waters exceeding that of the flood tide, by the addition of the natural discharge from the drainage of the country.

In the words of Playfair, in his illustrations of the "Huttonian Theory,"—"a soft mass of alluvial deposit, having its pores filled with water, and being subject to the vibrations of a superincumbent fluid, will yield to the pressure of that fluid on the side of the least resistance, that is on the side towards the sea.

"It is however but from a small distance that the waves are impelled against the shore with a progressive motion. The border of breakers that surrounds any coast is narrow, compared with the distance to which the detritus from the land is confessedly carried; the water, while it advances at the surface, flows back at the bottom, and these contrary motions are so nearly equal, that it is but a very momentary accumulation of the water that is ever produced on any shore.

"It is true, that bodies which float on the water, when carried along on the tops of the waves towards a shelving beach, having acquired a certain velocity, are thrown farther in upon the land than the distance they would have floated to, if they had been simply sustained by the water."

The breadth of the breakers depends upon the depth of the sea, as operated upon by the power of the wind upon its surface; and practically, we may generally assume, that waves do not break constantly, except in extraordinary heavy gales, where the depth exceeds five fathoms at low water spring tide, and that it is only an occasional sea which breaks in six or seven fathoms. May it not also be assumed, that the latter is to be attributed to the surface wave meeting the resistance of the back sweep of the previous waves, or what is usually termed the undertow?

An accumulation of shingle can alone take place in those situations where its progressive course along the shore is stopped, by the latter becoming from its form opposed to the direction of the prevailing gales from which the impulse is derived.

In other cases, the general result of the action of the surf in heavy gales of wind is the removal to the depths of the sea, of all detritus within its range.

If we extend our observations further, we shall find that the only materials thrown beyond the line of tranquil flotation consist of substances upon which the direct influence of the wind acts, such as timber, sea-weed, &c. all others of greater specific gravity, occupying the substratum of the waves, and being, with but few exceptions, carried out subsequently by their back sweep.

CHAPTER VI.

CONSIDERATION OF THE ACTUAL CONDITION OF RIVERS, WITH REFERENCE TO THE AUTHOR'S THEORY, AS DEVELOPED IN CHAP. III. ON THE CAUSE OF THE EXISTENCE OF BARS AT THE MOUTHS OF RIVERS.

THE Mississipi offers a remarkable instance of the presence of bars, and therefore demands a special inquiry into the cause of their existence.

With regard to this river, it must be remembered that it is but a small proportion of the immense volume of its waters which is discharged over what are called its six mouths, or bars. According to a recent survey, made by order of the government of the United States, we have no reason to be surprised that the Mississipi is, as regards its available navigable qualities, far inferior to even the Thames; the latter, being free from any bar, offers no impediment to the entrance of the largest class line-of-battle ships, at the lowest tides; whereas the following is the state of the entrances to the Mississipi.

The *Pas à Loutre*, the East Pass, the South-east Pass, and the South-west Pass, have each only twelve feet on their bars; the South Pass, eight feet; and the Grand Bayou only seven feet.

Notwithstanding the grandeur of the channel of the Mississipi, when confined by its natural boundaries, it acquires a new character on its extension into the nearly tideless Gulf of Mexico, and we may consider the circumstances attending the discharge of its waters to nearly resemble those which take place where the waters of a river are discharged into a tideless sea. If we also take into account the vast but ineffective portion of the backwater, which escapes seaward over the mud banks on each side of the many mouths of the Mississipi, we must conclude the remaining volume to be inadequate to maintain deep water through so many separate outlets as have been enumerated above, but of which the following is a more particular account.

The course of the channel of the Mississipi, below Port Jackson, runs between mud banks, deposited by its water, for a length of about twenty miles, with an average breadth of 2800 feet, and a depth of seventy feet, and this must be considered as all that is available for the purposes of navigation, that which escapes laterally over the mud banks being utterly useless.

At twenty miles from Port Jackson, the channel of the Mississipi becomes divided into three currents, taking respectively easterly, southerly, and south-westerly directions. Of these the easternmost, after a course of five miles further, is divided, the northernmost going under the name of the *Pas à Loutre'* and the other, *the East Pass;* and this latter, after running a further course of six miles, undergoes a second bifurcation, one channel continuing under its previous designation of the East Pass, and the other is called the South-east Pass.

The South Pass, after a course of five miles, is divided into two channels, one continuing seaward, under the same name, and the other known as the Grand Bayou.

The South-west Pass, or reach, runs seaward, with an undivided course.

Below Port Jackson, the course of the Mississipi is perfectly straight for the first twenty miles, or to what may be termed the commencement of the new delta, formed at the subdivision of the main channel, into the east, south, and south-western channels.

From this point, so great is the diversion of the course of its future currents, that there is a variation of fourteen points of the compass, between the *Pas à Loutre* and the South-west Pass; and their radii may be taken to average fourteen miles from the first bifurcation.

By a measurement from the survey, the northernmost mouth or bar, called the *Pas à Loutre,* is situated at the great distance of twenty-eight miles, in a direct line from the mouth or bar of the South-west Pass.

The floods of the Mississipi having power to discharge themselves into the gulf over the whole of the banks which appear only to limit their course when the river is in a low state, no difficulty occurs in accounting for the little depth of water which is found in the several bars of the Mississipi, notwithstanding the supposed gentleness of the slope of the surface of its waters.

It appears probable, that at no remote period, the waters of the Mississipi will, in lieu of taking their present direction, break out a new channel into the gulf, many miles nearer the shore than the present embouchures, and thus complete that conversion of the gulf into land, which is now proceeding more rapidly near the present mouths of the river.

In the Mississipi and Orinoco, the process of the formation of their lower channels is yet going on by the deposit which is taking place in the shallow and nearly tideless seas into which their waters are discharged; and we cannot, therefore, look upon *the deposit* at their mouths *as being bars* permanently established, such as we find attached to many rivers which experience no elongation of their channels.

Desirous of presenting the best information connected with the actual condition of the Amazon and Orinoco, I have extracted from the works of the illustrious Humboldt, all that has any reference to them, with a view to a subsequent consideration of how far their examples may also be considered to be favourable or opposed to my theory on the formation of bars.

In Vol. V. Humboldt states that

" The whole eastern coast of South America, from Cape San Roque, and particularly from the Port of Maranham, as far as the group of the mountains of Paria, is so low, that it appears to me difficult to attribute the Delta of the Oroonoco, and the formation of its soil, to the accumulated mud of one river. I do not deny that the Delta of the Nile, according to the testimony of the ancients, was heretofore a gulf of the Mediterranean filled up by successive alluvions.

" It may be easily conceived that at the mouth of every great river, where the velocity of the stream suddenly diminishes, a bank, an island, a deposition of substances which cannot be carried on further, is formed. It may also be conceived, that the river, obliged to flow round this new bank, divides itself into two branches; and that the accumulating earth, finding a point of support at the summit of the delta extends farther and farther, widening these branches. What takes place at the first bifurcation, may be effected in each partial channel; so that by the same process, nature may form a labyrinth of small bifurcated channels, which are filled up or grow deeper in the lapse of ages, according to the force and direction of the waters. The principal trunk of the Oroonoco has no doubt in this manner divided itself, twenty-five leagues west of the *Boca de Navios*, into two branches, those of the Zacupana and Imataca. The network of less considerable branches in which the river ends towards the north, and the mouths of which bear the name of *bocas chicas* (little mouths), appears to be a phenomenon entirely similar to that of the deltas of tributary streams.

"When a river, several leagues from the coast (for instance the Apure or the Jupura) joins another river by a great number of branches, these multiplied bifurcations are merely furrows traced in a very flat soil.

"It is the same with the *Oceanic deltas*, wherever the coasts, by general inundations anterior to the existence of the Oroonoco and the Amazon, have been covered by depositions of accumulated earth. I doubt whether all these *Oceanic deltas* have been gulfs, or as some modern geographers say, *negative deltas*. When the mouths of the Ganges, the Indus, the Senegal, the Danube, the Amazon, the Oroonoco, and Mississipi have been more carefully examined in a geological view, it will be perceived that they have not the same origin; the coasts that advance into the sea, from the effects of increasing alluvions, like the *deltas* of the Nile, the Ganges, the Danube and the Mississipi, will be distinguished from plains traversed by a few lateral branches, forming part of a soil of alluvions the extent of which exceeds several thousand square leagues.

"The Delta of the Oroonoco, between the Isla Cangrejos and the Boca de Manamo (the land inhabited by the Guaraon Indians) may be compared to the island of Marajo or Joanes, near the mouth of the Amazon.

"One of these pieces of alluvial land is on the north, and the other on the south of the principal trunk of the river. But the form of the Island Joanes is connected with the general configuration of the soil of the province of Maranhao, as the coasts of the *bocas chicas* of the Oroonoco are with that of Essequibo and the Gulf of Paria. Nothing appears to me to prove that this gulf extended formerly towards the south from the *Boca de Manamo*, as far as Vieja Guayana;

or that the Amazon filled with its waters the whole bay between Villa Vistoza and Grand Para. All that surrounds rivers is not their own work. They have most frequently scooped out for themselves a bed in alluvial lands, the origin of which dates from more ancient geological causes, from the great catastrophes which our planet has undergone.

"It is proper to examine whether between the bifurcated branches of a river the mud do not repose upon a stratum of pebbles which are found far from running waters.

"The greatest separation of the branches of the Oroonoco is forty-seven nautical leagues.

"This is the breadth of the *Oceanic delta* between Punta Barima and the westernmost of the bocas chicas. An exact survey of those countries is much wanted; the number of the mouths is not known.

"A vulgar tradition gives seven to the Oroonoco, and reminds one of the *septem ostia Nili*, so celebrated in antiquity. But the *delta* of Egypt was not always confined to this number; and eleven considerable mouths at least may be counted on the inundated coast of Guyana. The *Boca de Navios*; *B. de Lauran* (Loran, Laurent); *B. de Nuina*, two or three leagues west of the Isla Cangrejos, and two or three fathoms deep; *Boca Chica de Mariusas*, five leagues further, little known; *B. de Venguenia*; *B. grande de Mariusas*, very navigable; *B. de Macareo* (the channel of this name admits large vessels as far as San Rafael, where it issues from the principal trunk); *B. de Cucuina*, narrower, but deeper; *B. de Pederneles*, navigable; *B. de Manamo grande*, near the islands of Plata and Pesquero; *Boca de Guanipa*.

"After the *Boca de Navios*, which mariners recognise by the *Punta Barima*, the *Bocas* of *Mariusas*, *Macareo*, *Pederneles*, and *Manamo Grande*, are most useful for navigation. That part of the delta which extends to the west of the

Boca de Macareo is bathed by the waters of the Gulf of Paria, or *Golfo Triste.* This basin is formed by the eastern coast of the island of Trinidad; it communicates with the Caribbean sea by the famous mouths of the Dragon (Bocas de Dragos), which the coasting pilots have regarded, ever since the time of Columbus, though improperly, as the mouths of the Oroonoco.

"We must not be surprised to find the breadth of the principal mouth of the Oroonoco (Bocas de Navios) so differently estimated. The great island Cangrejos is separated only by a narrow channel from the inundated land, which extends between the Bocas de Nuina and de Mariusas, *so that twenty or fourteen nautical miles are obtained, according as the measure is taken (in a direction opposite to that of the current) from Punta Barima to the nearest opposite bank*, or from the same Punta to the eastern bank of the Isle of Cangrejos. *The navigable channel is crossed by a sand-bank or bar, on which are seventeen feet water, the breadth of which is supposed to be from* 2500 to 2800 toises. The Oroonoco, like the Amazon, the Nile, and all the rivers that separate into several branches, is less wide at the mouth, than might be supposed from the length of its course, and the breadth it preserves at some hundred leagues inland. It is known from the labours of Malaspina, that the Rio de la Plata, from Punta del Este, near Maldenudo, as far as Cabo San Antonio, is more than 124 miles broad; but in going up towards Buenos Ayres, this breadth diminishes so rapidly, that opposite the *Colonia del Sacramento* it is already no more than twenty-one miles. What is commonly called the mouth of the Rio de la Plata is but a gulf, into which the Uruguay and the Parana fall; two rivers much less considerable in breadth than the Oroonoco. In order to exaggerate the breadth of the mouth of the Amazon, the Islands of Marajo and Caviana are considered as comprised within it, so as to give the immense breadth of seventy leagues from the Punta Tigioca to Cabo del Norte, but an examination of the hydraulic system of the channels of the Tagypura, the Tacantius, the Amazon, and the Araguari, which unite the immense volume of their waters, is sufficient to show how chimerical this estimation is. Between Macapa and the western bank of the Island of Marajo (Ilha de Joanes), the Amazon, properly so called, is divided into two branches which together are only thirty-two miles broad. Lower down, the northern bank of the Island Marajo stretches east and west, while the coast of Portuguese Guayana, between Macapa and Cabo del Norte, runs from south to north. Hence it follows, that the Amazon, where the two islands of Masciana and Caviana are situate, and the waters of the river first come into contact with those of the Atlantic, forms a gulf nearly forty miles broad. *The topography of the Island of Joanes, and of the vicinity of Belem or of Para, has little accuracy in the most recent maps; the following is the real state of things. A very narrow channel (the Tagypura) issues from the Amazon below the Villa de Gurupa, and joins the Lake Annapu, near the town of Melgaço. The Rio Annapu, which is the Guanapu of D'Anville, falls into the lake. East of Melgaço, the Tagypura receives the great river of the Tocantins, on which stands the town of Para.*

" The flux and reflux of the tide in the Oroonoco are felt in the month of April when the river is lowest, beyond Angostura, at a distance of more than eighty-five leagues inland. At the confluence of the Carony, sixty leagues from the coast, the water rises one foot three inches. *These oscillations of the surface of the river, this suspension of its course, must not be confounded with a tide that flows up.*

" *At the great mouth of the Oroonoco, near Cape Barima, the tide rises to a height of two or three feet; but farther on,* *towards the north west, in the Golfo Triste, between the Boca de Pedernales, the Rio Guaripiche, and the western coast of Trinidad, the tides rise seven, eight, and even ten feet.* Such is the influence of the configuration of the coast, and of the obstacles which the mouths of the Dragon present to the running off of the waters, on points thirty or forty leagues distant from each other.

" All that is related in very recent works, on the particular currents caused by the Oroonóco at two or three degrees distance in the open sea, on the changes observed in the colour of the sea, and on the fresh waters of the Golfo Triste (*Mar dulce* of Gumilla), is entirely fabulous. The currents on the whole of this coast run from Cape Orange towards the north-west, and the variations, which the fresh waters of the Oroonoco produce in the force of the general current, and in the transparency and reflected colour of the sea; rarely extend farther than three or four leagues east north east of the island Cangrejos. The waters of the Golfo Triste are salt, though in a less degree than in the rest of the Caribbean sea, on account of the small mouths of the Delta of the Oroonoco, and the mass of water furnished by the river Guarapiche.

" The astonishing distance at which the little tides of the coast are felt in the bed of the Oroonoco, and of the Amazon, has been hitherto considered as a certain proof, that these two rivers have only a slope of a few feet during a course of eighty-five, and of two hundred leagues. This proof, however, does not appear irrefragable, if we reflect that the magnitude of the transmitted undulations depends much on local circumstances, on the form, the sinuosity, and the number of channels of communication, the resistance of the bottom on which the tide flows up, the reflexion of the waters by the opposing banks, and their confinement in a strait.

" The river Amazon swells periodically at the strait of Pauxis, 192 leagues from the coast.

" At the Oroonoco the tides of unequal height of *Punta Barima*, and of *Golfo Triste* are transmitted in unequal intervals of time by the great channel of the *Boca de Navios*, and by the narrow, winding, and numerous channels of the *Bocas chicas*. As these little channels separate at one point only from the principal trunk near San Raphael, curious researches might be made on the retardation of the tides, and the propagation of the waves in the bed of the Oroonoco, above and below San Raphael, at Cape Barima in the ocean, and at the Boca of Manamo in the Golfo Triste. *Hydraulic architecture and the theory of the movement of fluids in contracted channels, would alike gain from a labour, for the execution of which the Oroonoco and the Amazon furnish peculiar facilities.*"

Having to notice the observations made by other voyagers on the Amazon and Orinoco, it will be necessary, in order to reconcile apparent differences, to state, that in the Amazon, the periodical inundations commence in December, are at their maximum in March, and that the river is at its lowest state in the months of July and August. In the Orinoco, the periodical floods are much earlier, since they commence in April, are at their maximum in August, and their minimum in January and February.

It is well for the advancement of science that of the two most distinguished men who have recorded their labours in the new world, the attention of one, as appears in the previous extracts, has been more particularly given to the Orinoco, and the other, the intelligent Condamine, to the Amazon. I shall translate the account of his expedition into the interior of South America, so far as it will throw any light upon the subject of this treatise: commencing therefore from his journal, on the 28th August, 1743, when, be it remembered, the river Amazon was at its *minimum* state, he remarks, that on that day he

" passed, in descending the stream, the river Jamundas, which the Padre d'Acuña called Cunuris, and pretended to be that point where Orellana was attacked by those warlike women whom he called Amazons. A little lower, on the same side, we landed at the Portuguese fort of Pauxis (or Obidos), where the bed of the river is contracted to a width of 905 toises (fathoms). The flux and reflux of the sea are felt as far as this place, at least it is sensible by the swelling of the waters of the river, which is manifest every twelve hours, and which is retarded each day as on the sea coast. The greatest flow of the tide which I measured at *Para*, was scarcely ten feet six inches in spring tides; it follows then, that the river from the Pauxis to the sea, that is to say in 200 leagues of course, or 360 according to the Padre d'Acuña, cannot have more than ten feet six inches of fall; and this agrees with the height by the barometer, which I found at Fort Pauxis at fourteen fathoms above the level of the water, to be *within a line and a quarter* less than at Para on the borders of the sea.

" We can well conceive that the tide which is felt at Cape North, at the mouth of the river Amazon, cannot arrive at Pauxis (Obidos) 200 leagues from the sea, in less than several days, instead of five or six hours, which is the ordinary duration of the flood tide; and in fact, from the coast to Pauxis there are twenty stations which mark, if we may so express ourselves, the period taken up by the tides in ascending the river. In all these places the time of high tide is manifested at the same hour as on the coast; and supposing, for more clearness, that these different stations are distant from each other about a dozen leagues, the same effect of the tides will make it noticed in their intervals at all the intermediate hours; understanding that in the supposition of twelve leagues, there will be one hour later in the arrival of the tide, from league to league, in leaving the sea. It is the same with the ebb in corresponding hours. At all events, all these alternative movements, each in its place, are subject to daily retardations, as on the coast. This description of the progress of the tide by undulations takes place in a similar manner in the open sea; and it appears that the retardation ought to take place more and more from the point where the ebbing of the waters is felt, as on the coast.

"The manner in which the velocity of the tide decreases in ascending the river is thus:—two currents opposed to each other which we observe in the time of the flood tide, one at the surface of the river, and the other at some depth; two others, of which one ascends along the borders of the river, and is accelerated; while the other, in the middle of the stream, descends and is retarded; finally, two other currents opposed to each other which meet often in the vicinity of the sea in the lateral natural channels, where the flood tide enters at once by the two opposite sides. All these facts, of which I am unaware of their having been observed by many, their different combinations, many other circumstances connected with the tides, without doubt more frequent, and more varied than elsewhere; because in this river they remount to a greater distance from the sea, than in any other part of the known world, will occasion doubtless interesting remarks, and perhaps new ones; but to give less to conjecture, a series of exact observations are necessary, which would require a long residence in each place, and a delay which scarcely agreed with the just impatience that I was in to revisit France, after an absence which had already lasted nine years. I have not failed to examine, in the environs of Para, and in the neighbourhood of Cape North, another phænomenon of high tides, more singular than all the preceding, of which I will speak in its place."

In the voyage down the Amazon made by Lieut. Henry Lister Maw, R.N., we find no evidence of a tidal action in the Main or Western Channel, the river being during his passage at its *maximum* state of flood. In the month of March he arrived at Obidos (the Fort de Pauxis of Condamine, and described by him as the farthest point at which the oceanic tides are perceptible when the river is at its lowest state). At this place Lieut. Maw observes that "the river takes a turn from N. E. by E. to S. E. by East." An abrupt change in the course of the river, which would naturally point out this position, as one where an alteration might be expected to take place, the tidal wave having to encounter the increased head which the descending current forms above the curve, in order to overcome the additional resistance the latter causes. After passing Jupura our traveller's subsequent course was by what is commonly, but I believe erroneously, called the Eastern branch of the Amazon, adjoining which the city of Grand Para or Belem stands on the banks of the river Tocantins.

Lieut. Maw remarks, that "on leaving the main channel of the Amazons, and entering the narrow channel of the Tagypura, the effects of the tide become immediately manifest. There was first a rise and fall of about a foot and a half, or two feet, increasing as we passed down. The third or fourth day there was a rise and fall of four or five feet with regular ebb and flood currents." He further observes, that "the flood tide runs stronger than the ebb at Para, which is perhaps owning to the check given by the main current of the Maranon to the flood on the western side of the island Marajo. During spring tides the current runs at the rate of six knots, in consequence of which, and the heavy squalls from the same direction, it is necessary to moor with the best anchor down the river." "It is high water at full and change about noon, and the rise and fall of the tide is then eleven feet."

The "narrow channel of the Tagypura," which separates the island of Marajo from the main land, cannot be correctly viewed as an outlet of the Amazon, for such it is only during the inundated state of that great river, or when its surface at the mouth of the Tagypura is above that of the channel formed by the united waters of the rivers Guanapu, Tagypura, Tocantins, which therefore on the ebb tide draw with them a portion of the waters of the Amazon, by the narrow channels of the Tagypura, which latter channels Humboldt would describe as merely furrows traced in a flat alluvial soil.

The tidal division of the Amazon has been subsequently noticed by Lieut. W. Smyth, R.N. and M. F. Lowe, late of H. M. S. Samarang; those gentlemen state, that "on the 13th of May, 1835, we reached Santarem. During our stay we watched the river very narrowly to ascertain the effect of the tide, but could perceive none whatever; this might probably be owing to the swollen state of the river preventing it being affected by the tide, which is said to extend as far up as Obidos, which is twenty leagues above Santarem; we stayed four days at this place. On the night of the 16th of May, we left Santarem and got to Gurupa (situated about twenty leagues above the Tagypura) on the 20th, a distance of 200 miles. A few leagues before we got to Gurupa[1] the river appeared to be of much greater width than we had before seen; and we judged it to be as much as four miles across. This was the first place where we perceived any effect from the tide."

"On the afternoon of the 21st we entered the branch of the river which leads to Para, and reached the town itself on the 29th of May."

Of what has been hitherto described as the Eastern branch or mouth of the Amazon, little information

[1] Gurupa is about seventeen leagues above the mouth of the Tagypura.

had been obtained, upon which any reliance could be placed, until the production of the chart of the river Para, by Capt. Forster, R.N. who, in the year 1831, surveyed that part of the coast of South America. Of the importance of that chart it is merely necessary to state, that it renders the navigation of that great outlet of the waters of several rivers accessible to our largest classed ships, by pointing out that there exists a deep water channel between the Tigoca and Coroa Braganza banks, in lieu of using the old entrance called the Bar of Para, which lies between the Tigoca and Marguaree banks, where the greatest available depth is only four and half fathoms at low-water: whereas it appears, by Capt. Forster's chart, that there is a clear channel of nine fathoms in depth between the Tigoca and Coroa Braganza banks. The soundings shoal from the sea gradually up the river; so that, so far as regards the eastern channel of the Amazon, or at all events as regards the great outlet of the waters of the rivers Araguari, Guanapu, Tagypura, Tocantins, and several others which are discharged into this channel, it is clear that no bar exists to this which is usually known as the eastern channel of the Amazon. Capt. Forster states that the rise of tide in spring-tides at Para amounts to eleven feet, and at neaps to seven feet; and that it is high water full and change at 12 o'clock.

Of the western channel or entrance to the Amazon no accurate chart exists; but from Condamine's description, we do not find any notice of a bar. According to his barometrical observations, the tide at Pauxis (or Obidos), two hundred leagues from the ocean, attains the same horizontal elevation as at sea; and therefore the Amazon, with a fall of only ten feet six inches, or eleven feet, in a course of two hundred leagues, may be cited as a proof of the accuracy of Guglielmini's theory, that "*the greater the quantity of water that a river carries, the less will be its fall:*" *and* "*the greater the force of the stream, the less will be the slope of its bed.*"

The truth of the above appears manifest, when we reflect that the current is accelerated by the same laws which govern all other bodies; and that, while the velocity of the stream near its source, is principally due to the slope of its bed, the acceleration of the current in the lower division of the river, is due to the pressure of the higher parts; and that practically we may discard the dread that any injury can arise to the navigation of a river, from the absence of any considerable slope in the lower reaches of a river, whether at its surface, or in its bed.

The value of the improvement of a tidal navigation may be properly tested by the extent to which the level of the low water surface and of the bed, has been lowered.

In the preceding pages of this work, I have shown that the want of depth in entering the Mississipi, is principally to be attributed to the volume of its waters being distributed over so many outlets; and it is obvious, that the same cause may be assigned for the presence of bars at the numerous outlets of the waters of the Orinoco. It may be remarked, at the same time, that the contrary character is presented at the embouchures of the Amazon, which at its junction with the ocean has only three outlets, occasioned by the presence of the islands of Caviana and Machiana, which are nevertheless flooded during the periodical inundations of the Amazon. Similar advantages attend the discharge of the waters of the Guanapu and Tocantins, by the eastern channel of the Amazon, the main discharge being through the two channels surveyed by Captain Forster between the Marguaree, Tigoca, and Coroa Braganza banks.

The Orinoco, so far as regards the number of the outlets for its waters, and consequent inability to maintain any great depth at either, may be likened to the Mississipi. We find, from Humboldt, that the flow at spring tides is only three feet at the easternmost or main channel, called the Boca de Navios; whereas at the western outlets, or *bocas chicas*, in the *Golfo Triste*, the rise of similar tides is from eight to ten feet. That when the river is in its lowest state, the flux and reflux are felt beyond Angostura, or at a distance of eighty-five leagues from the coast, and that at sixty leagues from the coast, the water rises one foot three inches; but the illustrious observer adds, "*These oscillations of the surface of the river, this suspension of its course, must not be confounded with a tide that flows up.*"

The course of the Orinoco appears to be far more circuitous than the Amazon for a similar distance from the ocean, and therefore offers not only a much greater resistance to the progress of the tide, but also to the discharge of its own waters; hence we may calculate, that the slope of the surface of the Orinoco is much greater than is found in the Amazon, and possibly it may be ascertained, that much of the tidal influence alluded to, or the swelling of its waters, is to be attributed to the successive impulses which must be felt in the channel above the delta, by the retarded arrival of the tides which enter by the mouths of the Orinoco, west of the main entrance called the Boca de Navios, from which the westernmost is distant forty-five nautic leagues.

The Baron Humboldt and Condamine have recorded their opinion of the value of the information which would be conferred upon hydraulic engineering, by correct surveys and observations on the delta of the Orinoco and the lower channels of the Amazon, and certainly an intelligent British Parliament would not hesitate to grant the means to extend the present great utility of the hydrographical department of the Admiralty, for objects of such high interest.

I cannot close my compilation of the information which has been obtained of the Orinoco, without noticing that given by Mr. J. H. Robinson, in his journal of a passage up that river to Angostura, in February, 1818, when the river was in its minimum state. The few extracts which I shall make, will show that Mr. Robinson has proved himself a careful and useful observer:—

"Feb. 6.—On tasting the water about twelve miles distant from the shore, in a direct line with the Guyana river, found it still very salt.'—Calm at 12. A pleasant breeze springing up about three, P. M., the ship began to get a-head again, at the rate of six or seven knots. As we drew nearer the land, steering west, 10, 9, 9½, 8, 7, 6, 5 fathoms, in which we brought up for the night, probably about twelve miles distant from the shore. The current strong enough here to keep the ship stern to wind, setting directly out to sea. Slime and froth on the surface of the water, coming in lines from north-west, no doubt from the Orinoco.

"Feb. 7.—Weighed about nine, with a light breeze and strong current from the river, setting directly out to sea, rather inclining to the southward. Water still changing its colour, as we approach, first steering west, and then, as the water becomes shoaler, (¼ less 4, and 4 fathoms), steering west and by north, and West N. W., the land just clearly in sight, and the people of the mast-head now able to discover Cape Sabinita. Orinoco about twelve miles distant. Soundings, by the deep four.

"Tasted the water, and found it fresh and pleasant, as that of the Thames, softer if possible.

"At 11.—Shoaled our water to 3½ and 3 fathoms, sandy bottom, put the ship about, now lying S. S. E., regaining the mud bottom. It is now evident that we are a short distance to windward of the mud bank, and three or four miles to the southward of its point. Can discern the situation of the mud bank very clearly, from the light colour of the water over it. Put the ship about again, to get to the northward of the point, and gain the other side; ran for about three quarters of an hour, and having Point Barima bearing S. W. and S. ½ South, bore up and ran towards it, having 4 and 3½ fathoms water. Ship steering S. S. W. ½ W. the mud bank to windward, and Point Barima now straight a-head. Soft bottom. *Water on the bar a different colour to the main stream, same as on the mud bank.* Soundings, 3¼ fathoms. *Bar just a-head.* Now, on the bar, soundings as we proceeded 3 fathoms, ¼ less 3, 3, ¼ less 3, 2½, ¼ less 3, 2½, ¼ less 3, 2½, ¼ less 3.

Ship now lying S. S. W. 2½ fathoms, ¼ less 3, now S. and by W. ½ W. ¼ less 3. S. and by W. ¼ less 3, 2½. Island Cangrejos to leeward, bearing W. S. W. Main land now bearing S. S. E. Soundings, 3 fathoms, *now over the bar, the latter seven or eight miles in length.* Trees floating down the river. Crab island bearing W. and by S. keep her away S. W. Soundings, 3¼ fathoms, *bottom hardening,* 3¼ f.; keep her away rather more to the southward; keep her S. W.; soundings, 3½, ¼ less 4, 4, 4¼, 4½, 5, ¼ less 5, 5 fathom soundings. Pilot cutter along side, took a pilot on board. Anchored in 4 fathoms. *Weighed again to take advantage of the tide which was now setting up the river. It was about four o'clock, when we again weighed anchor, and proceeded up the river, with a* *pleasant breeze.* Ship steering nearly west, and the soundings 6 and 6½ fathoms, at six o'clock. Some time after, 7 fathoms. Approaching the island of Cangrejos, distant about two miles. Island now a-beam; soundings, 7¼, 7½, 8, 7¼ f. Ship going W. N. W. 8½ f., at nine, and *ten o'clock as we advanced.*

"*The current now running down at the rate of two miles an hour*, keeping extremely close to the right bank, often not more than two hundred yards distant, we deepened our water to 9, 10, 11, and 11½ fathoms. Continued all night going gently a-head against the current, until about five in the morning, when we anchored; current running down at the rate of two to three knots per hour."

The journal, which is throughout full of interest, shows that the progress up the river, on the 9th and 10th, was by one of the lateral channels, which are separated from the main one by a succession of islands.

"Thursday 11th.—Weighed about six, A. M.; almost calm, *but the current slackened, as it did also yesterday, towards the evening.*" "Near Sacupana the river about a mile in breadth.

"*As far as Barancas, there are three or four hours back current daily, but beyond that place it is invariably down*, excepting where the windings of the river form an eddy tide."

"Saturday 13th.—Came to a point near Guyana, where the river takes E. and W. and N. and S. direction.

"*We observed the Fort of Guyana upon a hill, and presently the village; anchored at four. The river rises and falls here daily about a foot.*"

The Fort of Guyana is about eleven nautic leagues above the first bifurcation or commencement of the Delta, and about fifty nautic leagues from the mouth of the Orinoco, near Cape Barima, called the Boca de Navios, where the rise of tide is described by Humboldt to be only three feet. This would then give a fall of only two feet in a course of fifty leagues, provided the high water level did not increase in elevation in ascending the river, or that it were not affected by the greater tidal elevation, which is found at the western mouths of the Orinoco.

The breadth of the main channel of the Orinoco, over its bar, is calculated by Humboldt to be from 2500 to 2800 fathoms, and in the extract from Mr. Robinson's journal, on crossing the bar, its length is estimated at from seven to eight miles.

This is so unlike the usual description of a bar, *with regard to its length*, that I am of opinion that a correct survey would discover a channel or channels, with a greater available depth. The Baron Humboldt gives seventeen feet as the depth on the bar of the Boca de Navios. At all events, taking into consideration the great width of the Boca de Navios, and the many other outlets for the waters of the Orinoco, it is unnecessary to seek to attribute to any other causes the diminished depth which is found at their entrance.

The Guayaquil, which is discharged into the

Pacific, has no bar at its entrance. The depth there is twelve fathoms, which depth shoals gradually to 3½ fathoms, at the city of Guayaquil, which is twenty-five leagues inland. The summer spring tides, which at the mouth of the river rise eleven feet, are felt above the city at Baba-hoyo, which is 24½ leagues higher up. The tidal course is, therefore, about fifty leagues.

In winter it is so swollen by the mountain torrents, that the tides are only perceptible in the reaches near Guayaquil.

It is high water at full and change at four o'clock, at the mouth of the river, and at seven o'clock at Guayaquil.

The soundings shoal gradually also up the Rio de la Plata, so that this great river is also unobstructed by any bar. Its mouth cannot, however, be considered to be beyond Point Indio on the south, and Monte Video on the north, notwithstanding the influence of the waters of the river seaward of those places.

The Congo has also no bar, in consequence of the gradual junction of its waters with those of the Atlantic, and upon this river an observation may not be considered out of place, with a view of correcting the too common error of estimating the discharge of the waters of a river, by basing the calculations upon improperly selected data.

Thus the late Captain Tuckey, R.N., when writing of the Congo, tells us " that the true mouth of the river is at Fathomless Point, where it is not three miles in breadth, and allowing the mean depth to be 40 fathoms, and the mean velocity of the stream $4\frac{1}{2}$ miles an hour, it will be evident that the calculated volume of water carried to sea has been greatly exaggerated."

The above calculation gives a discharge of 418,176 cubic feet per second; those previously made, and to which Captain Tuckey refers, giving a discharge per second of two million cubic feet. Nevertheless, Captain Tuckey's calculation gives for the discharge of the Congo a volume equal to that of the Ganges, but this estimate of his will be found to be equally exaggerated beyond the real discharge of the backwater of the Zaire or Congo, he, and preceding observers, having made their calculations from improperly selected transverse sections: they have in fact taken the sectional area of the estuary, or *tidal current*, united with that of the river, in lieu of the real discharge of the latter, or of the drainage of the country. The true discharge of the river must therefore be sought where it is found clear of tidal influence, or where the stream runs but in one direction.

At Casan Yellala, in the vicinity of which the tidal rise was observed to be eight inches, or one fourth of that at the embouchure of the river, the breadth was found contracted to a width of half a mile; but Captain Tuckey's own description of the

Congo at the falls of Yellala, when speaking of the volume of its waters, contradicts his calculations. "The principal idea," says he, "that the falls create, is, that the quantity of water which flows over it is by no means equal to the volume of the river below it, and yet, as we know that there is not at this season a single tributary stream sufficient to turn a mill, below the fall, we can hardly account for this volume, unless we suppose, as Dr. Smith suggests, the existence of subterranean communications, or caverns filled with water."

The long course of the contracted limits of the channel, above forty miles, does not warrant the above supposition. The existing navigable capabilities higher up the river, or above Banza N'Inga, are only due to the waters being dammed back by the obstructions below that place, forming the commencement of the rapid course of the river, along which the navigation is suspended.

The whole of the great rivers which are discharged into the North sea and German ocean, will be found to be free from bars where their state is in accordance with my theory; and the same may be said of those which are discharged into the English channel, or into the Bay of Biscay. (See Note at the end of this Chapter.)

Of the bars attached to the smaller rivers on the coast of Portugal, I am not personally able to speak; but doubt not of their being due to the causes I have assigned; but the Tagus, which forms one of the finest ports in the world, I could never look upon as a bar river, no survey of its mouth showing less than eight fathoms at low water; while, according to others, there is a navigable track of one fathom more: the North and South Cachops are but deposits on either side of the channel. Where so great a depth as eight fathoms exists at low water, we can hardly consider that a bar exists; but are inclined to think, that where a greater depth is found within the river, the latter is only due to its flowing in a more contracted channel.

The Gironde, which has six fathoms at low water at its entrance, cannot be looked upon as a bar river. Of the Gironde, I shall have to take further notice, on account of the bore which is formed in its tributary, the Dordogne.

The Rhone discharges its waters into the Mediterranean by *three* mouths. It deposits so large a quantity of earth at its mouth, that the lighthouse, built on the shore in 1737, is now above three miles from it. The great fall of the surface of the Rhone, is well known.

The Po, which discharges its waters by a number of mouths into the Adriatic, has more than any other river engaged the attention of the Italian engineers. The gravel rolled down by the mountain torrents has progressively raised its bed, parallel to which protecting mounds have been constructed, so that the Po in its lower course presents the singular spectacle of a vast body of water whose level is higher than that of the adjacent country.

The tide flows to Longastrino, which is only fifteen miles from the principal mouth of the Primaro, where there is a bar, having on it four feet eight at low water; within the bar the depth is from two to three feet greater. The bed of the Po is at Longastrino, eight inches below the level of low water on the bar, and the greatest slope of the surface of the river is observed to be in the lowest division, for about three and a half miles from its mouth. Above that distance the surface is visibly parallel to the bottom of the river.

If we add to the depth of the bed, that of a sixteen feet flood of backwater, we shall perceive how great must be the slope of the surface of the river in its lower course, remembering that at the mouth there is a free discharge which consequently assists to produce the rapid slope of the river above. These features are quite enough to account for the presence of the bar.

Ireland is justly celebrated for the excellency of her rivers, such as the Suir, the Lee, the Bandon, and the Shannon, which carry a long course of deep water.

In the *Nautical Magazine*, the pages of which are constantly recording a mass of useful information connected with maritime affairs and scientific objects, and from whose correspondents I trust I shall yet derive additional benefit by the communication of their local knowledge of the actual state of rivers, there was given in March, 1836, a "Description of Ballyshannon, properly called the river Erne, by Commander W. Mudge, R.N. (to whom the nautical world are indebted for some of the many beautiful maritime surveys, which emanate from the hydrographical department of the Admiralty). I shall extract from his account of this river, as it illustrates my theory on bars. "The approach to the river is impeded by a bar, called by nautical men the Bar of Ballyshannon, lying between the before mentioned points, Kildoney and Finner; it is nearly half a mile broad, composed of fine sand lying upon a bed of stones; the least water on the narrow channel over it, is three feet six inches on the middle of the bar; the outer part where the sea begins to break, having about nine feet, gradually deepening to seaward to four fathoms, so that the bar is not precipitous on either side, but progressively shoaling to the centre part, which is termed by pilots, the Patch, being that part with the least water on it. An endeavour has been made to remove this patch, which runs the whole width of the channel, but with what success I am not prepared to say, except from the information furnished by the people employed on the work, by whom I am told, that at the commencement of the operations there were barely eighteen inches on it, and at present there will be three feet and a half at low water.

"The principal object appears to be, to deepen the water over the bar by forming a straight channel, and removing a portion of the stones which lie under the sand, with the hopes that ultimately the strong ebb current will keep the channel thus made clear; how far this may answer the expectations of the projectors is a mere speculation, and, in my humble judgment, a very doubtful one, too. The two sides of the river are girded by sand, and particularly the south side is composed of vast sand hills, which furnish the river washing their base with abundance of drift sand.

"This is so intimately mixed with the current, that the water is quite discoloured by it; and, as of course it must be deposited somewhere, that place will be where the ebb stream meets with the resistance of the ocean, just outside the bar; so that were the present bar removed, or worn down by the increased velocity of the current obtained by the present contemplated effects, another bar would assuredly form outside of the present one."

"A grand obstacle to any improvement in this bar arises from the exposed position of the mouth of the river, which is directly open to the N. W., and consequently the whole Atlantic swell, uninterrupted in its course for more than 2000 miles, expends its mountainous billows directly on the bar. Is not this alone sufficient to form a bar? And where is there a river so circumstanced that has not one?"

The questions have been already answered in the previous pages by the examples which have been adduced, and Commander Mudge will easily supply many others without drawing upon any other information than his own; but to proceed, in order to show how much knowledge of the real state of a river is to be obtained by the observations of a scientific maritime surveyor.

"I must here premise, that the bar is only available at high water of a spring tide for a vessel drawing not more than nine feet; at such times there will be thirteen feet six inches, with neap tides only ten feet; but, generally speaking, the surf is so heavy on the bar, that crossing it is attended with much danger, and even at the best of times hazardous."

"Having described the approach to Ballyshannon, I may now observe that, from the bar up to the town, the river is clear from any obstruction, having a clear channel of from ten to twelve feet water up to the quays, where there are from three to five fathoms water, and room for a considerable number of shipping."

The following extracts I wish to particularly press upon the attention of my readers, as showing the real cause of the existence of the Bar.

"It now remains for me to speak of the tides which govern the ingress and egress to this port."

"*It is high water on the bar at 5h. 30m.* P.M.; *but the flood stream runs only four hours, and when the freshes* *are greatest, only three hours; and on some occasions, especially with neap tides, there is little or no perceptible flood stream. The ebb stream may be presumed to run out, that is generally speaking, from one hour before high water on the shore, till the first quarter flood upon the shore, or until the water has risen two feet on the bar.*

" *The rate of the ebb varies according to the time of tide:—the first quarter ebb will run four miles an hour, at half ebb nearly six miles an hour, and from that time till nearly low water, it is a complete rapid over the bar; indeed, I can compare the rapidity in a boat passing out, and the sensation experienced, to nothing but shooting the centre arch of old London bridge.*

" The rise and fall with spring tides are ten feet, with neap tides from four to six feet. With northerly or easterly winds there will be thirteen feet six inches on the shoalest part of the bar; but from one to two more with south or westerly winds.

" With neap tides there will be ten feet, and with south or westerly winds there may be from twelve, to twelve feet six inches on the bar.

" *From the bar half way up to the quay, the rate of the current is pretty equal, from three to two knots, but from thence gradually decreasing to something less than three quarters of a mile;* but with heavy rains the freshes run over the flood-water, and occasion a constant ebb-stream.

" It is high water at the town quays at 5h. 10m., twenty minutes before it is high water on the bar; this anomaly arises from the great discharge of water from the falls of Ballyshannon, accumulating and causing a higher level, and the flood tide damming up and preventing the free discharge of the freshes."

NOTE.—The rivers Thames, Humber, Dart, Elbe, Weser, Ems, Scheld Maas (the outlet of the waters of the Rhine), Shannon, Lee (Cork), Seine, Loire, Gironde, and Tagus, may all be cited as examples of rivers free from bars, in consequence of their condition being in accordance with my theory as developed in Chap. II. of this Treatise.

Again, the Yare, Esk, Tees, Wear, Tyne, Aln, Tweed, Lune, Wyre, Mersey, Dee, Liffey, and Ballyshannon, (*bar* rivers,) all present those features which prominently mark them out as illustrating the truth of my theory on the cause of the existence of bars, as advanced in Chap. III.

The above examples have been brought forward by me, because it is probable that many of them may be known to the reader. The accuracy of either may be easily tested by tidal observations, made in connexion with previously ascertained levels of the surface of the river at low water; this latter operation being in all cases necessary, in order to determine whether any or what portion of the rise of tide be due to the increased elevation of the high water surface, which occurs in many rivers above the oceanic level of high water.

CHAPTER VII.

ON THE COURSE TO BE ADOPTED FOR THE IMPROVEMENT OF THE DEPTH ON THE BARS OF RIVERS, AND IN THEIR CHANNELS.

THE reasoning in the preceding pages on the cause of the formation of bars, suggests the course to be adopted for their amelioration, by the removal of all those inner banks, or shoals, stretching like dams across the river, which have the effect of preventing the rapid discharge of the backwater during the proper tidal duration of the ebb. Where this is judiciously undertaken, an improvement must take place, not only within the river, but on its bar. Let us imagine a case to exist, (and there are many such within my own observation,) that at a distance of a few miles, say seven from the mouth of a river, the vertical rise of tide is diminished one fourth of that on the bar, or, in other words, is reduced from sixteen to twelve feet.

If therefore, by the operations which are undertaken, the original difference be lessened so that at the said distance of seven miles from the bar, the low water level has been made to subside three feet, giving a vertical rise of fifteen feet, where there was formerly a flow of only twelve; it is clear that a greater body of tidal water must enter, and that the period of the duration of the flood tide must be lengthened, while that of the ebb is diminished.

Viewing the river in one of its functions, that of a tidal receptacle, it must be admitted that this alteration in the constitution of the river must have the effect of creating a deeper channel, not merely by reason of the greater volume of tidal water which enters, but on account of the greater energy, or power to maintain a good channel, which is the peculiar result of an augmentation of the sectional area of the channel by an increase in its depth.

While thus urging the advantage which is to be gained by an increase of the flow of the tide, I must not be understood as objecting to those partial contractions of the lateral dimensions of a river, which in many cases are absolutely necessary to be executed in order to obtain the removal of the shoals which have the effect of diminishing the flow of the tide; I desire to press upon my readers' attention the importance of carefully estimating the comparative value of the sections of a river.

Of what use is it for the purposes of navigation to have a channel possessing great breadth, but destitute of the main desideratum, a sufficient available depth? Or, of what use is it for the purposes of navigation, if a river possess a wide extent of channel, but so shallow that nine-tenths of the volume of water which it contains do not pass over the available sailing channel? Again, of what advantage towards deepening the entrance of a river can a wide extent of shoal water possibly be, which is discharged into the ocean over the sand banks which are generally found on each side of the main current, or passage over the bar?

It is important to draw the distinction between the available and non-available portion of the tidal receptacle or channel.

An expansion of the waters of a river beyond its regular limits can only be of service, when the contents of the increased tidal receptacle pass subsequently over the bar, and when that expansion is not attended with the formation of any shoal, and consequent diminution of the vertical rise of tide.

Seeing that the existence of bars is to be attributed to the too great declivity of the bed of a river, or to that of its low water surface, the impropriety of forming dams across a tidal river, with the view of converting it into a line of navigation by the means of locks, ought to strike every reflecting mind as a measure which should never be adopted when there exists any possibility of obtaining the requisite depth of water by deepening the bed of the river.

By the removal of all dams, weirs, and shoals, offering an obstruction to the free passage of the tidal and land waters, an increased sectional area, or general augmented navigable depth, must be obtained; in this case nature is assisted: but when weirs or dams are made across tidal rivers, the certain result must be a diminution of the depth, or value of the navigable channel below the obstruction.

1st, Because the tidal receptacle is diminished;

2ndly, Because the period of the duration of the flood tide is reduced, and that of the ebb lengthened;

3rdly, Because these dams or obstructions prevent the rapid discharge of the backwater, or land-floods, upon which the depth of the navigation mainly depends. Nor does the evil stop here; for be it remembered, that the natural result of the formation of any dam across a river must be a rapid deposit in its bed, as well above as below the obstruction.

The formation of any dam across a tidal navigation gives but a temporary advantage to the upper country, while permanent injury or ruin is inflicted on the lower navigation.

Let us imagine, that in lieu of following the principle which was recommended to the inhabitants of Glasgow by Mr. Golborne, C. E. in 1768, to whom is due the merit of the great improvements in the Clyde, the system of constructing dams, forming a still water navigation, had been adopted, as previously recommended by Smeaton; viz. "to form a dam across the river at Marlingford with an entrance lock for barges drawing four feet water." Is it not certain, that in lieu of the town of Glasgow having the present advantage, that vessels of fourteen feet draught are able to get up to Glasgow, the paltry barge navigation must have driven the whole of the important trade of that city lower down the river to Greenock[1]?

If it should be argued, that the adaptation of the principle of converting the tidal into a still water navigation arises from a desire to economize the resources which are available, this position will not hold good, because of the great annual charges which must be incurred to keep the navigation clear both above and below the dam, the natural result of the formation of the obstruction being that of raising the bed of the river above and below it, or of preventing a great portion of detritus being carried down stream.

[1] In the Appendix is given an account of the engineering proceedings in the Clyde, forming a report by me to the Committee of the Tees Navigation Company, by whom I was sent to get the fullest information on the subject in the month of September, 1833.

CHAPTER VIII.

ON THE CAUSES OF THE EXISTENCE OF SHOALS IN THE BEDS OF RIVERS.

Shoals will be found wherever there are irregular increases of the lateral dimensions of the stream, and they are therefore formed necessarily in a greater or less degree wherever the current crosses obliquely from shore to shore, or, in other words, the bed of the river will be shoaler where the current receives an augmentation of its lateral dimensions in passing diagonally across the channel in its passage from one concave shore to another, the real breadth of the stream having to be estimated at right angles to the line of its direction as it crosses from side to side. If therefore the breadth of the current be increased, its depth must be diminished in order to equalize the sectional area which the river is capable of keeping open. The more abruptly this transition of the current takes place, the greater will be the extent of the evil, or the diminution of the depth of the channel.

Wherever the channel is divided by an island or sand bank, shoals must exist in the bed immediately above and below the obstruction, from the cause first assigned, viz. a local increase of the width of the stream.

Where shoals exist in a tideless stream, independent of the above causes, they will be found to be owing to the presence of some geological features of the bed, or to its being of too firm a nature to be acted upon by the current when unassisted.

In tidal rivers the same causes account for the existence of shoals, but the following are to be added.

Where the slope of the river is too great, an obstacle is offered by the strength of the ebb to the passage of the young flood, which consequently seeks to make its way along the shore, where it meets with less resistance than in mid-stream.

The early flood thus produces the lateral channels which are so commonly met with in tidal rivers. Between these lateral channels and the main stream, an eddy is formed by the opposition of the two currents, in which situation a sand bank is invariably formed. These sand banks tail down with the ebb, and generally unite with the shore at the upper end of the reach, or where there is an eddy produced within the complement of the angle of reflection made by the ebb.

Opposite the tail end of these shoals, or at the commencement of the lateral channels, there will always be found a diminution of the depth in the main channel, the width of the stream being greatest in that part at low water.

Shoals will always exist where the main current of the flood tide runs in a different bed from that of the ebb.

Shoals also exist wherever, from the geological features of the country through which the river passes, its waters have the power at any particular spot of expansion over a natural inlet, such as Jarrow slake on the Tyne, and the Potatoe garth of the Wear, as it is called; both of which diminish the tidal receptacle, though they are believed by many to have a contrary effect.

The only use of such expansions is to promote tranquillity within the port; but to effect this object it is unnecessary to compromise the navigable depth, as is permitted in the river Wear, though there is little there to spare.

The observations which have been made on the cause of the presence of bars at the mouths of rivers, as well as of those shoals which may properly be called their inner bars, point out, that by the adoption of correct engineering principles, a reasonable expectation may be formed of an amelioration of the depth on the bar, and in some cases of its entire removal. While with respect to those inner bars or shoals, which are equally injurious to the navigation, no doubt can exist of their permanent removal in many cases, and of their amelioration in all.

The importance of being able, by these operations, to gain even a few feet of available depth in the navigation up to any place of trade, is so great, as to demand a few more observations on the subject; because, in every way in which it may be considered, advantages present themselves to urge the adoption of the means which are available to ensure an increased vertical flow of the tide to towns situated on the banks of navigable rivers, as well as an additional depth at low water; the combination of which advantages will be found to be almost equivalent to bringing the place of trade nearer the sea. No moving power is so cheap and advantageous as that produced by a tidal navigation, which is, at one and the same time, the road that carries and the locomotive power.

A correct survey of the river, with longitudinal and transverse sections, as well as tidal observations, having made manifest the extent of the existing impediments, whether owing to natural or accidental circumstances, the first question which will arise is, whether the evils are of merely a local nature, confined to isolated portions of the navigation, and therefore only requiring express works for their removal? or, whether the river from long neglect has been allowed to so far widen its channel, as to require a systematic contraction to obtain an increased navigable depth?

In the first instance, or where a shoal or bar exists without any apparent augmentation of the general width of the stream, the current also continuing in a course parallel to the banks of the river, we may be satisfied that the shoal consists of some geological feature which the current, when unassisted, has been unable to wear down to the general level of its bed; here dredging operations will prove effective; as we shall not in this case fall into the oft-repeated error of attempting to remove shoals by dredging, without first providing against the possibility of their re-accumulation by attacking the cause of their formation; the following is an example:—

"DREDGING IN THE THAMES OFF WOOLWICH [1]."

"*The Thames.*—It is a remarkable fact, that notwithstanding the enormous sum of 125,000*l.* was employed in dredging the river Thames off Woolwich between the years 1808 and 1816, the river is now in as bad a state as ever, and the mud and silt is accumulating instead of decreasing; in 1816 alone as much as 29,000*l.* was thus expended, and the sum amounts on an average to 16,000*l.* per annum to such little purpose."

Now the causes of the existence of the shoals off Woolwich are only such as I have combated with,

[1] See Nautical Magazine, July, 1840.

and permanently removed, in numerous instances, and generally without having been obliged to have recourse to expensive dredging operations.

The whole of the shoals off Woolwich may be permanently removed, giving at least three feet increased available depth of water in the channel, and that too at less outlay than has been uselessly incurred in this instance in a single year for dredging. This may be effected without the possibility of injury to any other portion of the river above or below the shoals, while at the same time the naval station at Woolwich would be benefited.

Very great improvements may be also made in the channel above London Bridge.

If the bed or shoal consist of a material capable of removal by the action of a stronger current, the use of a dredging vessel and her establishment, may be often dispensed with by the construction of works, with a view temporarily to contract the channel, and thus increase the velocity and consequent scouring action upon the bed.

In the instance where the shoal arises from an irregularity in the width of the river, we may be certain that a judicious contraction will increase the depth; but that without this being effected it is equally clear, that all attempts to deepen the navigation by dredging operations, will be found to be a pure and gratuitous waste of the resources of those interested in the improvement; because the removal of the cause of deposit not having been effected, the shoal, as a matter of course, must speedily resume its original appearance.

If we inquire why so little has been effected in the improvement of many navigable rivers, notwithstanding the great outlay which has been annually incurred in the employment of dredging vessels, we shall always find that those who have directed their use, have contented themselves with operating upon the effect, what medical men call "treating a symptom," in lieu of attacking the cause, and thereby permanently removing the effects.

The great objection which has been raised against the attempt to improve the navigable depth of rivers by the aid of lateral contractions, or of works constructed for the purpose of properly directing the current, has arisen from the belief that a diminution of the tidal receptacle must be a necessary consequence; and upon this view (in every sense superficial) of the case, many engineers, who in their profession have deservedly attained great eminence, have not hesitated to give their strong, but in my opinion erroneous, advice against any interference with the navigation of rivers except by dredging operations.

So widely have these opinions been promulgated, and so deeply rooted are they in the minds of many, that in order to correct them, it becomes necessary to refer directly to their authors, as well as to the localities which have been alluded to; so that the opinions which I have ventured to promulgate in these pages, as the result of an inquiry after truth, may be subjected to the severest test, that of public candid criticism, aided by local information.

By the adoption of this open course, one advantage will be gained, that of discussion, which might be restrained were my theoretical and practical observations less frankly expressed.

The river Wear, under the management of the late Mr. John Rennie, and subsequently of Sir John Rennie, offers a complete illustration of the state of a river in which the principle hitherto constantly acted upon for the improvement of its navigation, has been that of dredging operations for the removal of the shoals, without any simultaneously constructed works to prevent the renewal of the deposit; in this little river, therefore, two powerful dredging vessels are constantly employed.

The late Mr. Rennie made a survey of the Wear by desire of the Commissioners, and upon that survey he laid down arbitrary "quay lines," as they are termed, for the guidance of the Commissioners, which are held up "as of the utmost value and importance, since they define the limits of the river, and, they say, will be the means of preserving the integrity of the navigation for the use of the public."

Now the Commissioners of the Wear would doubtless set a much higher value upon this plan, which, *de facto*, prevents the possibility of any permanent improvement of the navigation, were it not for the immense annual charge which it entails upon the port, to get that accommodation for shipping by constant dredging operations, which accommodation would however be better, more economically, and permanently secured by a few simple works to remove the cause of the formation of the shoals; and by devoting their remaining ample means to the construction of wet docks, which are necessary to give due encouragement to the high commercial enterprise for which the port of Sunderland is renowned.

That the late Mr. Rennie's great mind was not fully made up on this subject, is proved by a reference to his reports on the Clyde, in the improvement of which river that celebrated engineer was consulted, and in which report he recommends the principle of contracting the channel of the Clyde, as originally proposed by Mr. Golborne, in 1768, and acted upon subsequently with such complete success.

The river Tyne may be cited as an example where, although an enormous income is available for the improvement of its navigation, the timid principle of "non-interference with nature," as it is termed, has been adopted, and where the navigation is consequently in a naturally unimproved state; and this is not owing to any want of desire on the part of the corporation of Newcastle to do their duty, but because their efforts or wishes have been paralyzed and overlaid by the professional opinions which I have cited: and here again the great name of the late John Rennie has been a barrier to improvement. We find that in 1816 the corporation employed Mr. Rennie, who in his report, says: "There is perhaps no river in Great Britain on which it is more difficult to give a satisfactory opinion as to the best mode of improving its navigation than the Tyne. In this river not only is great depth wanted, but likewise great width, to accommodate the immense number of ships which resort to it.

"These two qualities, however, are incompatible with each other. If the width of the river were to be contracted by a solid embankment, its depth would be increased, but then the space for the accommodation of shipping would be lessened; and as a less quantity of tide water would thereby be admitted, it would have less effect in keeping down the bar. But this is not all; for when ships are working into the harbour with an adverse wind, and flowing tide, there would be less current to carry them across the bar; so that in gaining depth of water in the channel of the river, care must be taken that the depth on the bar be not diminished.

"A solid embankment on the side of the river must therefore be avoided, or at least be limited to a certain extent, and other means devised to effect the object. But to both these there is a limitation;

and therefore it becomes a nice point to settle with precision what depth can be obtained and maintained in the river Tyne, between its mouth and Newcastle Bridge, without contracting it to a degree that may prove materially injurious to the navigation."

Now, though at the risk of being charged with presumption in setting my humble, but decided opinion, against that of one who, in his lifetime, was held second to none in his profession, and whose numerous works will remain monuments of his genius, yet the importance of the subject forces me to encounter severally the arguments advanced; because it is clear, that their ill effects are yet felt in checking efforts for the improvement of the navigation of rivers; and if I too, am in error on this subject, possibly I may be set right by his talented successors. My sole object is the attainment of truth.

The first statement advanced by the late Mr. Rennie, in his report, is, that "the accommodation for shipping would be diminished by any contraction of the river."

This opinion I have no hesitation in saying is at variance with fact. Indeed, instead of such an event occurring, the very reverse would be experienced; because it is notorious that the wide expanse of shoal water in the Tyne offers at present no accommodation for shipping. By a judicious partial contraction, more than one half of that now useless expanse would become deep water, and therefore available. The result of an examination of the state of the navigation of the Tyne shows that, at low water spring tides, there are shoals, several having on them only a depth of from eighteen inches to three feet? This is the state of the best portion of the navigable channels. Of the rest a vast expanse dries at low water.

The second statement made by the late Mr. Rennie, is, " that by a contraction, a less quantity of tidal water would be thereby admitted."

The best reply to this will be a recurrence to facts, which exhibit a great existing difference of flow or rise of tide at the bar, as compared with that which takes place at Newcastle upon Tyne, which incontrovertibly proves that the want of contraction in certain divisions of the river causes the existence of dams or shoals, which prevent the free discharge of the back water, and consequent full ingress of the tide.

The third position taken by Mr. Rennie was, " that the result of a contraction would be a diminution of tide water, and therefore less effect in keeping down the bar."

This objection is also met by a reference to the difference of flow existing between Newcastle and the bar, and it is certain that the removal of the shoals in the Tyne, by a contraction effected at the expense of its shallow expanses, would cause a considerable depression of the level of the river at low water, and consequent augmentation of the tidal receptacle in its most useful dimension, depth.

The last statement is, that the consequence of the contraction would be "less current to carry vessels across the bar." This objection to a judicious contraction, is also the result of an erroneous theory, as the real effect would be an earlier and unobstructed entrance of the current of the flood tide, consequent upon the depression of the level of the surface of the river at low water. It may be safely assumed, that the greater the difference between the amount of the rise of tide at Newcastle, as compared with the rise on the bar, so much greater will be the difficulty or obstacle to the early entrance of the tide; and, by my theory advanced in the preceding pages of this essay, the greater the existing difference, or the greater the declination of the stream at low water, the worse will be the state of the bar of the Tyne, or of any other river.

The difference between the rise at Newcastle and that on the bar, amounts to about 3 feet 6 inches, whereas in a properly improved state of the navigation it should not be 12 inches, and as with this augmentation of the flow, a greater sectional area and depth would be maintained at low water, the importance of an alteration in the state of the Tyne, which would allow the access to the quays of Newcastle of the largest vessels which now pass over the bar of the Tyne, will be readily acknowledged.

The duration of the flood tide at Newcastle, is, "according to Dr. Rotheram, 4½ hours, and that of the ebb, 7 hours." Now were the inner bars or shoals removed, not only would the tidal receptacle be increased, but the discharge of the augmented volume of the ebb tide would take place in a shorter period, and consequently with additional power to keep down the bar.

Although the removal of the shoals must thus succeed in obviating the difficulty which now exists of access to the quays of Newcastle, by large class merchant vessels, this advantage cannot be obtained without adding to those which are at present experienced at North and South Shields, from the proximity of those towns to the embouchure of the river; and this, by reason of the simultaneous production of increased depth on the bar, and facility of entrance to the port.

As the object of this essay is merely to point out the principles proper to be adopted for the improvement of the navigation of rivers, and not to enter into unnecessary details, I will now refer to another river in which immense capabilities exist for improvement, viz. that of the river Lune to Lancaster, which may be cited as another example, in which a bad bar is occasioned by the too great declivity of the bed, and surface of the river, at low water, and consequent unequal duration of the flood and ebb currents.

In the year 1838, a very excellent survey of the river Lune was made by Messrs. Robert Stevenson and Sons, accompanied by accurate longitudinal and transverse sections of the river, and a report on the improvements proposed by those gentlemen. From that report, which was published in the Lancaster Guardian, we gather, that at Lancaster the flow at an ordinary spring tide is about 10 feet, and at Glasson, five miles nearer the Irish sea, the rise is 21 feet, making a difference of flow or declination of the surface of the river of 11 feet in that short distance, caused solely by the obstructions to the ingress of the tide.

The high water work is on the same level at both places, and the time of high water nearly the same. In spring tides, the tide takes one hour and fifty minutes to flow from Glasson to Lancaster, or, in other words, it takes that time to overcome the fall of 11 feet, which exists at low water between Lancaster and Glasson.

In neap tides, the tide takes five hours to flow from Glasson to Lancaster.

At Glasson, spring tides *rise for* 3 *hours* 20 *minutes*, and fall *for* 7 *hours* 40 *minutes ;* and neap tides rise for 6 hours, and fall for 6 hours.

At Lancaster, spring tides *rise for* 1 *hour* 40 *minutes*, and fall for 4 *hours* 10 *minutes*, and neap tides rise for 1 hour and fall for 2 hours 40 minutes.

In their report, the Messrs. Stevenson say, "The great object to be kept in view in carrying into effect the improvement of the navigation of the Lune, is the free admission of the greatest possible quantity of water from the sea, *as reliance must be chiefly placed upon the scour produced by the tide, and not upon the current of the freshwater, as the chief agent in keeping open the navigable channel of this river.*"

The report proceeds to recommend the fords or shoals to be dredged away, and certain projecting points to be cut off. "In this way a still greater volume of tide water would be admitted to flow freely up and down the river, and the passage of the tide from Glasson to Lancaster would be proportionably accelerated, while the navigation would be rendered more easy for the increased number of vessels, which, after the deepening of the channel to sixteen feet, would come directly to the quays of Lancaster.

"The reporters are aware that some doubts may exist as to the possibility of preserving the above depth of sixteen feet, when once obtained, but after a careful examination of the river itself, both by boring and otherwise, they have no hesitation, from their experience on other rivers, in saying that the occasional use of the dredging machine, assisted by the natural scour of the tide, passing four times over the river in twenty-four hours, will preserve the depth and breadth of the channel which they have recommended to the consideration of the commissioners."

It will be seen, from the above extracts, that the Messrs. Stevenson do not aim at the destruction of the cause of the formation of the several shoals; they however provide the necessary constant use of dredging vessels.

These gentlemen have adopted the theory, "that reliance must be chiefly placed upon the tidal water to keep the navigation clear to Lancaster." Without further discussing this theory at present, it is enough, in reference to the Lune, to state that about half a mile above Lancaster there is a weir across the river, for the purpose of obtaining water power for a mill, by which weir a barrier is put to the ingress of any tidal water, except during extraordinary spring tides; and, in my opinion, to the presence of this weir is mainly due the bad state of the channel at Lancaster. If this weir were removed, and the dredging operations, recommended by the Messrs. Stevenson, were accompanied by the simultaneous construction of works to properly confine and direct the current, then, and not till then, would there exist a good, permanent, deep water channel to Lancaster.

In order to maintain deep water at Lancaster, it is requisite to remove all obstructions above, as well as below the town, so as to allow the free discharge of the backwater, upon which agent the depth in the channel really principally depends.

The surface of the river should, throughout its tidal course (*its natural tidal course*), be reduced to the lowest possible level.

The attention of the Messrs. Stevenson appears not to have been directed lower down the river Lune than Glasson, where there is a dock at the entrance of the Lancaster canal. I will therefore give a short description of its remaining navigation.

The Lune continues its course for two miles below Glasson, at which distance it debouches from the land, and takes its remaining direction for about four miles and a half through sands which are uncovered at half tide. The course of the channel through these sands is represented by a segment of a circle, described with a radius of about six miles; a form which, if protected on its concave side, would insure a permanent deep channel at low water.

From a consideration of the data furnished by the Messrs. Stevenson, it is evident that their views for the improvement of the navigation should have included the channel below Glasson; thus those gentlemen tell us that "the spring tides rise at Glasson for 3 hours 20 minutes, and fall for 7 hours 40 minutes." Hereby affording proof, that for above two hours and a half the flood tide is only swelling, in order to overcome the fall of the river between

Glasson and the bar, where the rise of spring tides amounts to twenty-seven feet, in lieu of being able to take an upward course on the turn of the tide at sea. These obstacles to the tidal influx, are principally situated in the first two miles of the channel below Glasson, the navigable tract through which is extremely circuitous.

Taking into calculation the short course of the navigation of the Lune, from Lancaster to the outer buoy at the entrance of the river, we must admit that, were care taken to render the natural advantages of the situation available, the result of a judicious system of improvement would be a rise of above twenty feet at Lancaster in spring tides, accompanied with a considerable depth at low water. If advantages existed in the Clyde, which were subsequently made available by the enterprise of the inhabitants of Glasgow, certainly much greater ones, and of easier accomplishment, may be secured by those interested in the trade of Lancaster and its neighbourhood.

The land floods to which the river Lune is subjected are so excessive, as to leave no doubt of their capability of removing all shoals, consisting of sand, or sand and small gravel united, were the energy of the current properly directed.

It is to be borne in mind that, by the removal of the weir and shoals, the floods would be discharged in less than half the period of their present duration, and therefore with an augmented power to keep the channel clear.

In the Dee, which is a *bar river* possessing all the peculiarities I have defined, we have another example of the injury which has resulted from allowing the formation of dams across the channel. A very interesting account of this river appears in the *Nautical Magazine*, for the months of February and April, 1838, to which I refer my readers, as containing, in a report by Sir John Rennie, the fullest information on that river. I shall therefore now merely give those data, which will enable the reader to form an opinion of the great extent of its available natural advantages, and of the degree to which they have been injured by the formation of the weirs in its course, for the purpose of obtaining water power. In reference to the present state of the navigation, the conclusion to which Sir John Rennie arrived, as appears by his report, was to recommend the formation of a ship canal from Chester to Heswell, in lieu of attempting to improve the navigation of the river.

The canal was to have a depth of twenty feet, and was estimated to cost 560,000*l.*

It appears from Mr. Remington's survey, that, during spring tides, the rise of tide at the point of Ayre is 29 feet 6 inches; at Flint, 23 feet 11 inches; and at Chester, 13 feet 8 inches.

The distance between the Point of Ayre and Flint is eleven miles; the declination of the stream at low water is therefore about the rate of six inches per mile.

The distance between Flint and Chester is thirteen miles, and the declination of the stream at low water is therefore about the rate of nine and a half inches per mile.

Now, if the declination of the surface of the river in this latter course were only reduced to six inches per mile, of the easy execution of which no doubt can exist in the mind of any practical man, the rise of tide at Chester, due to the tidal water alone, would be 17 feet 5 inches; this might be effected by simply giving a proper attention to the channel between Chester and Flint.

Happily for the interests of the trade and district of Chester, a more extensive field of improvement is open, which requires only the resumption of those rights of navigation from which the public should never have been debarred; and though those rights may have been lost, there can be no doubt of Parliament's authorising their resumption, on fair compensation being made to the present proprietor of the dam or weir above Chester-bridge, either by purchase, or by the supply of the substitute of steam power for the Dee-mills.

The injury to the navigation of the Dee dates from the early period of the formation of this dam by Hugh Lupus, earl of Chester, about the time of the Conquest. In the 17th century, the dam or cause-way became a subject of much litigation, in consequence of its supposed prejudicial effects on the river, by its impeding the free access and discharge of the tidal and upland waters, and thus preventing them from scouring the harbour from the accumulating sands. The evil has been allowed to exist, although its simple removal would have effected more benefit to the navigation up to Chester, than has arisen from all the sums which have been otherwise expended by the Dee Company upon their works.

That the rise of tide at Chester in spring tides amounts to no more than 13 feet 8 inches, when at the point of Ayre, within a distance of twenty-four miles, there is a flow of 29 feet 6 inches, cannot be a matter of surprise, when it is borne in mind that this weir is situated immediately above Chester, and that the same tide rises on it only 4 feet.

If this weir were removed, the river would soon have its bed scoured out many feet lower than at present, and the flow at Chester would become at least 20 feet in lieu of 13 feet 8 inches at spring tides, attended with a corresponding depth at low water, so that ships of the largest class would have free access to Chester.

Having already noticed the Lune on the north, and the Dee on the south of the Mersey, it will be necessary for me to allude to that river, though at the risk of being thought tedious, in my endeavours to direct in a proper train the views of those interested in the improvement of the navigation of rivers.

The last account of the Mersey and Irwell navigation appears in a pamphlet by Mr. H. R. Palmer, in which that eminent engineer has fully made known his own theories, and invited discussion upon them, which are indeed supported with his usual talent and ingenuity.

In page 14, Mr. Palmer says: "The subject of the tideway of the river Mersey between Liverpool and Warrington has undergone frequent discussion, and is one of great importance, not only to the navigation of it, but also to the port of Liverpool itself. Various professional men have from time to time, during the last twenty years, given their opinions with reference to restrictions for the regulations of the banks; it is therefore incumbent on me to dwell largely on the subject, and I hope not altogether without effect, in removing some very strong impressions, formed by a coincidence of expressed notions. It is, however, much to be regretted, that on a subject which involves so much scientific inquiry, the reasonings upon which opinions have been founded have been so scantily explained."

Mr. Palmer ably shows, that so long as the current of the river is allowed to vary in its track through the wide expanse above Liverpool, having several channels, neither can have the depth which would be due to a single and permanent one. But he adds:—

"But to obtain that degree of regularity or parallelism which is required, certain excrescences in the area must be enclosed, by which it will become reduced. It is to the consequences of such a measure that the numerous opinions before adverted to were directed, and which have now to be considered.

"It has been asserted, that the open broad areas of the river at a considerable distance above Liverpool, are necessary for the maintenance of deep water towards the river's mouth; and it is thence inferred, that if the area of the river towards the extremity of the tideway were diminished, great injury would be sustained towards the outfall.

"The shoals are said to accumulate, and the depth of the channel to diminish; and a great proportion of such effects have been attributed to the enclosures that have been made from the river in the upper part of the tideway."

In reply to the above, Mr. Palmer writes thus: "I have confidence in being enabled to prove, that the great expanses in the area of the upper part of the river are not only not beneficial to the outfall, but that they are injurious to it."

To support this statement, Mr. Palmer proves that the accumulation of sands in the vicinity of Runcorn (above and below that place) is greatest when there is least water descending from the uplands.

He adds: "Such is the amount of accumulation in one dry season, that it is felt by those who navigate the upper part of the tideway. It is then to be observed, that the accumulations progressively increase until the arrival of a land-flood, on which occasion the excess that had become deposited is removed. The fact therefore is, that the quantities of accumulations in the river are inversely in proportion to the quantities of rain; and hence there is less deposit upon the bed of the river in the tideway, when the greatest quantity of silt is brought down from the uplands. *From this reasoning we may infer, that if there were no descending land-stream, and if the whole area of the tideway were a* MERE BAY, *the same would gradually silt up, and become dry land.*"

"Such would be the fact, and it will be shown, that however extensive the receptacles for the mere tidal waters, they do not contribute to the preservation of the outfall."

"The cleansing of the outfall is admitted by all to be dependent upon the force of the *outward* motion of the water. It must therefore follow, that the *inward* motion of the same (*i. e.* the flowing tides) will act in a similar manner, and bring with them such quantities of sand as they are capable of moving."

"*The question, then, refers to the comparison of the inward with the outward forces. If the force of the ebbing tide do not exceed that of the flowing tide, it is evident that no greater quantity of sand can be carried* *out by the former than that which is brought in by the latter. If the ebbing water have an excess of power over that which flows, it is certain that a greater quantity of sand will be carried out than is brought in, and, consequently, the depth must gradually increase. But such, however, is not the fact, although the ebbing tides are assisted by the waters from the uplands.*

"*From what has now been stated, I trust it will appear manifest, that the* EFFECT *of the flowing tides in raising the bed of the river, exceeds that of the ebbing tides; and hence we may conclude, that the depth of the channel is entirely and exclusively dependent upon the water derived from the uplands.*"—Palmer.

I have underlined that which Mr. Palmer evidently considers the strength of his argument, which is indeed so plausibly and ingeniously expressed, that to refute it, it is necessary first to separate the tidal from the river agency, in order to better ascertain if his argument can be maintained,—*that the tidal force of the flood to bring in sand exceeds that of the ebb to return it.*

Now, if this were true, all bays, all deep indentations of the coast, which depend solely upon the tidal agency, must have filled up ere this, since Mr. Palmer, as a geologist, must allow that sufficient time has elapsed for the purpose.

If, according to his reasoning, it must follow that bays should deepen if the force of the ebbing waters exceeded those of the flood, by the same argument they should fill up if the force of the flood, or power to bring in sand, exceed that of the ebb to return it.

So far it becomes a mere consideration whether a reference to facts will, or will not, establish Mr. Palmer's statement,—"that the flood-tide brings to the shore more sand, than the ebbing of the same body of water is able to return."

Mr. Palmer does not demonstrate WHY the flood tide ought to bring and deposit more than the ebb is able to carry back to sea.

In the preceding pages of this essay, I have shown from Playfair, that the progress of all detritus is in a seaward direction, because of the incline of the shore, or that the line of the least resistance is seaward, and consequently the power of the ebbing waters to return all sand brought by the flood tide must be greater, by reason of that declination or fall of the shore.

If it be assumed in reply to this, that as a consequence of that argument, all bays must deepen, or "the depth must gradually increase;" the answer will be, that this does not necessarily ensue, since another force exists which restores the equilibrium; that force is the tempest, which but for the inclination of the shore (and consequent back sweep) would make every coast a gaining one.

Another reason why the ebb tide (abstractedly from all connection with land water) exceeds the flood in power, may be found in the fact that the surface line of high water declines from the shore towards the offing, the rise of tide in the offing being less than on shore.

As a general result we may then conclude, that where a mere tidal agency solely exists, there is no tendency to alteration as to depths, or no tendency to deposit, since an uniform declination of the shore secures a return to sea of all sand brought on it by the flood tide.

The argument which I have advanced, of the increased power of the ebb tide to remove sand brought in by the flood tide, holds good only so long as the advantage of the slope of the bed exists, and this will be felt in all rivers which are unobstructed by bars. Where bars exist at the mouths of rivers, the declination seaward ceases on the summit of the bar; and the power of the ebb within the bar to restore to the sea the sand brought by the flood tide must prove insufficient, unless assisted by the force of the upland waters; and therefore, wherever expanses exist which have the effect of slackening the energy of the backwater, or which are the means of occasioning the formation of shoals, which impede the rapid discharge of the backwater, then such expanses, such as those alluded to by Mr. Palmer, must have the effect of giving a greater influence to the flood tide than could exist if the land floods were able to discharge themselves in a shorter period.

Wherever expanses are found which have the effect of creating shoals, and thereby preventing the full flow of the tide, we may be sure that the navigation below would be improved by their enclosure.

If it could be shown to me, that in the expanses alluded to above Liverpool their presence is not attended with an extraordinary rapid diminution of the vertical rise of the tide, and also an obstruction to the rapidity of the discharge of the upland water, then I should at once admit that their enclosure would be injurious: but what is the fact? Why that at Liverpool the rise of tide is thirty-three feet when at Runcorn there is only sixteen and a half feet, and at Warrington eight feet; so that in lieu of the flood tide taking an early course up the river, it is dammed back, and deprived of its natural flow by the obstructions which it meets in the channel.

From Liverpool to Runcorn the distance is only about fourteen miles, yet there is a loss of sixteen and a half feet in that short distance: the difference would not be two feet were the course of the channel confined within proper bounds; so that though there would be a decrease of the tidal volume, as regards its lateral dimensions, there would be a great increase of the same when measured vertically.

So far as regards a judicious enclosure of those expanses, or the formation of works to produce a permanent low water channel, I coincide in opinion with Mr. Palmer, provided simultaneous operations are carried on so as to increase the tidal influence further up the river, by the removal of all weirs from its course, as far as the tidal current could be made to extend, and also in reference to the execution of the cuts planned by that gentleman to shorten the length of the navigation. If these views were acted upon, the rapid discharge of the backwater or upland floods and tides, as well as the increased vertical flow of the tide far up the river, would more than compensate for the proposed partial enclosure, or construction of works to confine the current in a permanent direction. *Were these views carried into effect the bar of the Mersey would be improved.*

No enclosure should be allowed beyond that which is requisite to bring the contained tidal waters within the influence of the backwater or upland floods; and where this influence is not felt, or where the effect of the expanses is only the creation of eddies, we may say that in such parts of the estuary the process of embankment or abstraction from the tidal receptacle is naturally going on.

Mr. Palmer states he cannot imagine a doubt to exist upon the fact, that "*the depth of the channel is entirely and exclusively dependent upon the water derived from the uplands.*"

Now if that gentleman had not coupled with the above statement, his opinion that "*the effect of the flowing tides in raising the bed of the river exceeds that of the ebbing tides ;*" and if he had not also said, "*that however extensive the receptacles for the mere tidal waters,* *they do not contribute to the preservation of the outfall;"* we might have remained uncertain that he did not rather mean to have expressed himself, *that the depth of the channel is entirely and exclusively dependent upon the preponderating effect derived by the discharge of the upland waters,* which in my opinion is the truth; and that so long as that effect can be brought to bear upon a large mass of water or tidal receptacle, great benefit must be derived from the presence of the tidal waters; *because we must bear in mind, that the latter during the ebb are hurried seaward with a greater velocity, by reason of their union with the upland water, than that by which they enter in the flood tide, and consequently they do materially aid in the preservation of the depth of the outfall.*

The consideration then is, how can we most effectually assist to put this mass of tidal water in rapid motion on the ebb? The reply must be, by giving a free discharge to the upland waters, by the removal of all weirs or dams from the channels of rivers, whether those dams be artificial or natural.

It has been already seen, that my opinion is opposed to the formation of the weirs proposed by Mr. Palmer to be made across his improved line of navigation, as I am generally favourable to the course of the latter; but with it I should adopt bolder views for the amelioration of the navigation of the river, and such as must meet the cordial co-operation and support of those interested in the permanent establishment of deep water in the lower division of the Mersey. In lieu of following Mr. Palmer's plan of forming a cut through Cuerdley Marsh, and placing across it a weir at the short distance of only two miles from Runcorn, I should in the first instance merely recommend the execution of the proposed cuts to shorten the navigation between Bank Quay, near Warrington, and the east side of Butcher's Field Lock, by which Mr. Palmer succeeds in reducing the length of the navigation in that distance, from about eleven and a quarter to only four and a half miles.

A short cut should also be made to prevent the circuitous course of the channel half a mile below the junction of the Mersey and the Irwell, to which distance a tidal navigation may be established by the removal of the whole of the weirs, and assistance being given to the operation upon the bed by the land floods of the united rivers.

From the junction of the Mersey and Irwell, the distance to Runcorn will be only fourteen miles by the improved channel.

The tide now flows to Woolston Weir, which is distant $12\frac{1}{4}$ miles from Runcorn by the present circuitous navigation.

When we take into calculation the resistance offered to the tidal stream, by the extraordinary circuitous direction of the channel, and the presence of the weirs and shoals, new views spontaneously suggest themselves for the improvement of the navigation; and we naturally desire to see its channel first freed from the injurious effects of the weirs themselves, (made originally for the purpose of obtaining water power,) and then to see *how far that channel may be improved by shortening its circuitous course, and assisting the land floods in wearing down its bed?*

Possibly it may found that the outlay, which would have to be incurred to effect this, would be less than by the adoption of a series of expensive new weirs and entrance locks, with all their attendant annual expenses.

It is also probable that, with this view of the question, Mr. Palmer may be so enabled to arrange the new constitution of the river by a general reduction of the bed, and attendant lowering of the river's surface, between Manchester and the junction of the Mersey with the Irwell, as to require only a single lock in addition to the entrance lock and dam, forming the proposed pool, or harbour, at Manchester.

From Runcorn to Manchester, the distance by the proposed new course is only about 22½ miles, and when we take into consideration that the rise of the bed in that distance is not so great as to amount to a prohibition of its reduction, on account of its attendant expense, it does appear to me that the obstacles at present existing to a tidal navigation to the vicinity of Manchester for sea-borne vessels, are not such as may not be certainly surmounted by the enterprise existing in that great centre of commerce, and that the expenditure would bring remunerative results also to the Mersey and Irwell Navigation Company.

In order to get rid of the objection against the formation of weirs, Mr. Palmer suggests that they should be made " self-adjustable, so that, according to circumstances, the bed of the river would be acted upon during longer periods, and therefore more effectually cleansed."

The reader has probably witnessed the beneficial effects which have ensued to the navigation of the Thames, by the removal of old London Bridge; and when he recollects that the construction of weirs across rivers produces a still more injurious effect than the piers of a bridge, by reason of the increased obstruction which they occasion, I believe that I shall succeed in drawing with me opinions on this subject, in coincidence with my own. In M'Culloch's statistics, there is the following good record of the ancient and present state of the Thames. " The removal of old London Bridge has caused a considerable change in the river Thames, and also, though in a less degree, below the bridge; owing to the contracted arches, through which the water had to make its way at the old bridge, there was a fall of from 4 feet 9 inches to 5 feet, at low water.

"This fall is now reduced to about two inches, so that the low water line above the bridge is nearly five feet lower at spring tides, than formerly; in consequence, *a greater increased body of tidal water now flows up and down the river, and as it meets with no obstructions, it flows with a decidedly greater velocity.*

"*The effect of this is to scour and deepen the channel of the river;* its influence, in this respect, being sensibly felt as far up as Putney Bridge, 7½ miles from London Bridge. The shores above the latter, that were formerly foul and muddy, are now becoming clean shingle and gravel; and near low water, the beach is quite hard and firm. The shoals are also decreasing below the bridge, and there can be little doubt that the change will, at no distant period, be felt from the Nore up to Teddington. Before the removal of the old bridge, a barge, starting from the pool with the first of the flood, could not get further than Putney Bridge without the assistance of oars; but, under similar circumstances, a barge now reaches Mortlake, four miles further up, *before* using oars, and with a little help she may reach Richmond, and taking horses there may get to Teddington in a tide. The descent down the river has been equally facilitated."

The examples which have been given of the benefit to be derived by the adoption of means to lower the beds of rivers will, it is hoped, assist to remove the long existing prejudice, that lateral contractions have always the effect of diminishing the tidal receptacle, or of injuring the navigation. We find that the shoals they are designed to remove, act as effectually as barriers to the ingress of the tide, and egress of the upland waters, as any lateral contractions would, provided their formation did not produce the effect of scouring down the bed; so that, although to the superficial observer a lateral contraction appears to diminish the tidal receptacle, yet a further investigation shows a great increase of the tidal receptacle, by the augmentation of its vertical dimensions; or, in other words, the diminution of the width of the current will be more than compensated by the subsidence of the level of the river at low water, thereby admitting a greater rise of the tide.

It must also be remembered, that a correct appreciation of the value of the alteration will not be made by solely taking into calculation the relative sectional areas.

A correct calculation will have regard to the total quantity of water passing and repassing through the channel, in a series of tidal observations, extending during neap as well as spring tides, the united volume and effect of which will far exceed that produced by tides which are only occasionally available.

The lateral contractions which are requisite to be made, are generally formed over that part of the bed of the river, which is only covered during spring tides, or where the depth is little, even at high water.

By the increase of flow, resulting from the removal of the shoals or inner bars, the mass of water in motion will be able to maintain a greater depth at low water than previously, or when the vertical flow was less.

By the removal of the bars, the velocity of the current at the bottom of the stream will be greatly increased, and with it the power to carry seaward all sand or other materials.

A shallow, but rapid current does not possess that capability of removing obstructions which appertains to deeper streams; of this we find notice in the "*Scrittori dell' aqua*," the Italian writers on hydraulic engineering having long been aware of the power of rivers, which though possessing but little fall are yet able to maintain deep channels, which quality they have termed the energy of deep waters.

It must be recollected, that no scouring action upon the bed of a river can be brought to its greatest effect without protecting the sides of the channel, upon which latter the current more easily works than upon the bottom, on account of the velocity on the latter being less than on the surface at the sides. Another reason exists in the fact, that the bed usually consists of heavier materials than are found nearer the surface.

In tidal rivers, the lower reaches of which run through a district of alluvial formation, we generally find that in order to obtain an increased navigable depth, a general lateral contraction becomes necessary.

In many rivers we find an augmentation of the width of their lower reaches occurs to such an extent, as to show that the increase is not due to the relative quantities of water passing through each section, but rather to the want of the protection to shores, which are in these parts subject to the strong action both of the flood and ebb tide, whose successive erosions soon waste the banks where they have not the protection of the aquatic plants which flourish where the tidal waters do not preponderate.

Where this undue augmentation of the width of a river occurs, and the principle of a general lateral contraction is acted upon in the lower reaches, it does not follow as a matter of course, as is imagined by some, that any injury to the navigation can be experienced, either at the bar of the river, or in any part of its course; but the reverse will happily be found to be the case: because, if the works be well arranged, a much greater useful body of the tide will be brought to act upon the channel and the bar; and the only portion of the tidal receptacle which will be abstracted, will be that which now flows seaward, not in the channel of the river, but over the sands on each side of the main channel and bar, and consequently without producing any useful effect.

In conclusion, in reference to the important subject of the consideration of the effect which will be produced by the partial inclosure of tidal receptacles in rivers, it must be remembered that this operation should never be permitted, unless it be satisfactorily proved that the existence of those expanses has the effect of materially diminishing the tidal receptacle further up the river, by creating shoals or inner bars which elevate the low water surface, and thus prevent the full influx of the tide and the rapid discharge of the backwater.

In constructing works for the purpose of accelerating the velocity of the current, to enable the latter to act upon the bed, it will be found advisable (where easily practicable by the use of timber jetties), to raise them up to the level of high water, in order to gain the utmost scouring action, or deep water energy of the current; and this may be done, even though it be determined, *a priori*, to subsequently reduce their level.

CHAPTER IX.

ON THE FORM TO BE GIVEN TO THE AMENDED COURSE OF A RIVER THROUGH AN ESTUARY.

This will depend upon the navigable depth which it is necessary to obtain for the trade of the port. Where the flow at neap tides, added to the depth at low water, is sufficient for the draught of the vessels in which the trade is carried on, a straight channel will be preferable, if compatible with the initial directions of the flood and ebb currents; but this is seldom the case, and we must therefore be careful not to be found warring against nature.

Where the rise of the tide during the neaps is too small to allow the port to be navigated by vessels of the required tonnage, it will in some instances be found that the advantage may be gained, or the end effected, by giving a preponderating direction of the stream to one side of the channel; or by rendering the latter slightly concave, making the reach a segment of a circle, described with a very large radius.

By this plan several important advantages will be secured, and we shall insure the preservation of the channel in the same bed, by means of a single pier, or line of shore, by reason of the current always seeking to escape at a tangent to the curve.

The above may be put in practice in deepening a channel through an estuary or tidal receptacle, where a prejudice exists against any contraction of the area at high water, by the formation of double lines of piers or embankments.

The action of the current upon the concave shore will establish a greater depth in the channel at low water than could be maintained in a straight channel, over the whole breadth of which there would be an uniform distribution of depth.

By this arrangement the required available depth may in many cases be obtained during neap tides for vessels of the desired draught, while during spring tides the extra flow will give sufficient even over that portion of the bed, the use of which is compromised in neap tides, in order to increase the depth on that of the other.

This plan of forming a single pier, presenting a concave face to the stream, may be acted upon with great effect where it is desired to force a passage through a bay encumbered with sand or shingle banks, such as exist at the mouth of the Rye.

If this plan had been adopted in the Liffey, it would have been found far superior to the present arrangement, being in fact the best form which can be adopted for piers at the entrance of small navigable rivers.

An examination of the plans of the entrances of nearly the whole of our rivers, where the hand of man has been applied, leads us to the belief that the form best calculated to insure deep water in the channel had not entered into the consideration of the projectors of the piers: indeed, cases of modern construction are to be met with, in which the very worst form has been adopted; viz. that of giving the windward pier during prevailing gales a convex figure next the channel, or, what is tantamount to it, the pier has been made with a deflexion outwards; the effect of which is a deposit of sand or shingle at the very entrance of the river, in order to avoid which, vessels when trying to enter are in danger of being thrown to leeward of the harbour.

The plan which has been adopted for the direction of the main pier at the port of Swinemunde, (one of the mouths of the Oder,) is based upon correct principles, which, if followed, would have added to the navigable value of many of our shallow sea ports; and though a pier were thus formed merely of piles and sheet-piling, it would be found more valuable to commercial interests than the splendid masonry which we see almost rivalling the massive ancient architecture of Egypt, but, like it, subject to be overwhelmed by an accumulation of sand.

The harbour of Swinemunde is formed by the river Swine, a name given to one of the outlets by which the Oder discharges itself into the Baltic; the influx itself is bordered on both sides by piers or moles, which stretch in a concave direction towards the N.N.W. into the sea, and render thereby the passage for ships sailing into the harbour as safe as possible, even while violent gales are blowing from the N.E. and E.N.E.

The depth of water in the middle of the navigable track is at least 18½ English feet when the river is at its ordinary height.

The eastern mole, which presents a concave face to the course of the stream, and its exterior or convex side to the N.E., from which quarter the heaviest gales are experienced, was made in 1824, and appears fully to answer the object of obtaining deep water along the whole of the course between the piers.

The western, or old pier, is considerably shorter than the eastern pier, and indeed is of very little service, the concave pier producing the desired result of deep water.

To the error of forming piers either rectilineal or convex, where they ought to be made concave to the action of the current, is frequently to be found another material one, arising from the want of attention to the direction of the current of the ebbing waters where they first come in contact with the pier or piers of the port. Thus, in the example of a river whose lower reach makes an acute angle with the coast, the construction of a pier in a rectangular direction with the line of coast must be followed by the formation of a second pier parallel to the first, in order to counteract the wrong set of the current, which, by the error committed in the direction of the first pier, would merely impinge upon its inner division and then rebound, leaving the pier faced with a long bank of sand or gravel in lieu of deep water.

Whenever, therefore, the lower reach of a river approaches the sea shore otherwise than at right angles to it, and it is determined to construct a pier or piers, the latter can only be economically and successfully formed by a judicious attention to the direction of the current above; and if this be acted upon, the construction of a second or parallel pier will seldom be found necessary.

To place in a stronger light this error, which has been so frequently committed, in the direction which has been given to piers, it is only necessary to follow up the comparison by treating the channel made between them as forming a new reach of a river. In this view, I doubt whether any scientific man would venture to defend a plan for the direction of a new channel or cut to shorten a navigation, if the same were not adapted by its form to the course of the current in the upper and lower reaches.

Having adapted the pier to the direction of the current in the lower reach of the river, and thus secured a true deep water current alongside of the former, all that is requisite will have been effected, provided its form be such that its interior face be not open to the direction or inset of the waves of the prevailing gales. Thus, supposing the lower reach admitted the construction of a single pier, whose exterior or convex side would be opposed to the prevailing gales, its figure would cause the outer division of the pier to flank, or shelter the interior of the port, and thus prevent the range of any seas along the face of the pier or quays.

By the plan of directing the energy of the current along a concave shore, formed by a continued pier, embankment, or by detached jetties, whose termini range in the required segmental figure, we allow the current liberty of expansion when in its swollen state; and when we reflect upon the process by which a channel is kept open, we shall be led to consider this system as the best which can be acted upon. The channel which is adapted to a river swollen with land-floods, must have a greater sectional area than its waters are able to maintain clear of shoals when the river is in its ordinary condition; hence we find that during the latter period a diminution of its sectional area must always take place. This sectional area is again augmented by the action of the upland floods, which often break out new channels, leaving isolated banks of sand or islands in mid-channel.

If however we limit the action of the current to one of its natural boundaries, we shall insure a much greater available depth than can be obtained by the formation of a perfectly straight line of navigation.

By this arrangement the river has full liberty to spread on one of its sides, and we are also enabled to ensure a permanent deep channel by the construction of a single pier or protected shore.

Those who are acquainted with the laws which govern the motion of water, will see nothing startling or objectionable in the proposition to substitute the plan of concave shores or piers described with very large radii, for the rectilineal ones now generally constructed; as, in order to obtain a permanent direction of the current, it will not be necessary to describe the line of channel with a less radius than three miles: and in practice this will be found to insure a really more direct and easy navigation, than is generally found to exist in reaches which are formed by parallel straight shores, but through which the navigable track frequently varies from shore to shore, and thus enforces a far more circuitous track. Thus in many reaches, which are apparently straight, we find the current rebounds from shore to shore, owing to the wrong set of its initial direction on entering the reach.

For every change of the course of the current, or for each angle of incidence which it makes with the shore, a loss of navigable advantage must result; the additional friction or obstruction to the discharge producing the effect of damming back the stream until it acquires a sufficient head to enable it to overcome the impediments to its course.

Wherever abrupt changes or elbows exist, connecting the several reaches of rivers, we should endeavour to make the union more easy, either by cuts through the convex shore, or by the construction of works on the concave side of the bed of the river, to have the effect of wearing away the opposite point or convex shore, and thereby leading the current through a larger curve in its passage from reach to reach.

Two plans present themselves to effect this object; the first is, by the formation of a new line of embankment faced with stone, or by that of timber breastworks in the required curve, connected with the upper and lower reaches; the second plan is by running out rectilineal piers or jetties from the concave shore, by which the same result will be effected at a small cost in comparison with that of the former described plan.

By the adoption of the construction of rectilineal jetties, we shall only have the expense of maintaining in repair their termini, which should be protected with stone, and this will prove a sufficient check against any future inroad of the current.

These jetties consist of main piles, placed at intervals proportioned to the tenacity of the bed into which they are driven, connected together by wale pieces, and closed in with sheet piling. It need hardly be observed, that practical information on this subject will enable a great saving to be effected in the amount of materials and labour required, and that generally it may be remarked that the position of each jetty depends upon the direction or set of the current. Cases of error on this subject have come under my notice professionally, in which isolated breastworks have been erected without paying a due attention to the initial direction of the current in the upper and lower reaches; the result of which has been, that the stream, in lieu of impinging upon the several breast-works, sets right into the spaces between them which were meant to have been converted into solid ground, and thus an intricate navigation has been produced.

CHAPTER X.

ON THE DIRECTION OF WORKS FOR THE PROTECTION OF THE BANKS OF RIVERS FROM EROSIONS

THIS subject will be best discussed by first bringing forward the generally received opinions on the subject. Frisi, in his work on Rivers and Torrents, in Book III. Chapter III. on the resistance opposed to rivers, informs us that "Famiano Michelini, in his Treatise on the Direction of Rivers, is the first author who has written on the defences that might be opposed to waters; although he has not formed a correct idea of the pressure, which, even in standing waters, arises simply from the depth. Barattiere, in treating of spurs (jetties) has laid down no rules on the mode of placing them: he merely takes it for granted, that they ought to be fixed where the corrosion is the deepest; whereas, on the contrary, it is easy to see, that one ought to begin to turn off the current at the very edge of the erosion, and that the spurs fixed lower down should be so placed, and at such proportional distances, that they might mutually support, and be supported by, each other.

"Guglielmini and Zendridi have treated this subject in a superior manner. By following up their common principles, the most advantageous position that can be given to a spur, for turning the current of a river towards the opposite side, may easily be determined. For supposing, in the first place, that the direction of the water is parallel to the banks, and resolving, by the common rules of mechanics, its velocity into two others, the one perpendicular, and the other parallel to the spur, the latter velocity will be proportional to the cosine of the angle which the spur forms with the under bank.

"Then, further, as the quantity of water that impinges against the spur is proportional to the perpendicular, drawn from the point or outer extremity of the work to the bank, or to the sine of the same angle of inclination, the quantity of motion with which the stream will flow in a direction parallel with the spur, towards the opposite shore, will be as the product of the sine into the cosine of the angle which the work makes with the bank: and since this product is a maximum, when the angle is half a right angle, it clearly follows, according to the principles above quoted, that the most advantageous position which can be given to a spur or buttress, is that in which it forms with the under bank an angle of forty-five degrees."

In accordance with the views which have been expressed above, the usual practice has been to form spurs or jetties with a considerable inclination down the stream, the angles which the works make with the lower banks varying from 45 to 20 degrees.

Now supposing that the descending particles of which the stream is formed, which first encountered the obstruction offered by the spur, were succeeded by others taking a precisely similar direction, then the theoretical views advanced by Guglielmini and others, would practically be found correct, and jetties so constructed would be found unobjectionable.

But a great oversight has been committed, in neglecting to observe, that wherever a jetty or spur is constructed, so as to offer a direct obstruction to the current, no such action upon it can possibly take place, as is advanced by the authors before quoted, an eddy being immediately formed above the work, which effectually protects the latter from all shocks from descending masses of ice, or roots of trees, which are either drawn quietly into the triangular eddy or space formed between the shore, jetty, *and new line* of shore, or are driven into the channel without the possibility of reaching any other than the extreme point of the jetty.

Thus in practice, the very form condemned so long, offers the greatest security which can be required, and that which is theoretically deemed the best by so many engineers is really the worst; inasmuch as all jetties constructed otherwise than at right angles with the shore, or approaching that direction, must have their entire lengths subject to shocks from all materials brought down on the surface of the current; an evil to which those constructed at right angles to the shore, are not subjected.

The triangular space above a jetty, constructed at right angles with the shore, is speedily converted into land; so that we have only to calculate upon the necessary durability of the work while this object is being effected by the deposit within the eddy.

Having thus demonstrated the superiority of the new system, even when applied to the construction of the uppermost of a series of jetties, it will be readily seen that those succeeding should be constructed in the same manner, and that by following this arrangement a great saving of their original cost of construction, and of annual repairs, will be effected.

To these jetties no degradation can take place, except at their extreme points, and even on the latter it will nearly cease on the completion of the new line of shore, ranging along the outer points of the jetties or spurs. This is the result of my own practice; that which attends the system of oblique jetties, recommended by Frisi and Guglielmini, and generally adopted even now, shall be described in the words of the former:—"But even by these means one can never prevent the water, impetuously striking against the angles and projecting points, and beaten about in various directions, from forming deep excavations, which by degrees will weaken, and at length overset, the work. I have seen great whirlpools in the Danube, and in the Adige, and in other rivers, at those spots where the bulwarks, and the shores, were struck most forcibly in front. I have uniformly discovered gulfs and eddies in the vicinity of the best constructed spurs."

The cheapest plan which can be adopted for changing the direction of rivers will be found by constructing the whole of the works of timber, and for this purpose the most ordinary kind of timber will be found sufficient to effect the object required.

This system of forming jetties by driving into the bed of the river main piles, framed together and closed in with sheet-piling (flanking), will be found to be of one-third of the general cost of works executed in clay and stone, particularly where there is a great rise of tide to be encountered; and further, because the works in clay, having usually to be advanced out from the shore, generally produce the effect of increasing the action of the current upon the bed, which latter, if consisting of sand or mud, will deepen rapidly, so that the cubical contents of the new embankment or jetty will exceed often by threefold, that which would be required to be deposited on a bed which is too firm to be acted upon by the current, except when moving with extraordinary velocity. By the use of those means, which are familiar to the practical engineer, timber construction may be raised for many hundred feet in length, over even what is called live sand, without producing any scour upon the site of the work, and consequent augmentation of its expense either in materials or labour.

By leading the current in accordance with those rules which govern its motions, and thus acting in obedience to, in lieu of in opposition to those laws, we shall always succeed in making the course of rivers subservient to the hand of man.

The same principles which should govern the alteration of the course of a river, which has a breadth of a few hundred feet, should also be strictly acted up to, where we have to lead and bend to our uses, the mass of waters of a river of great magnitude. We see in the operations of nature how by the occurrence of trivial circumstances, such as by the accidental lodgment of a few roots of trees, a change is commenced in the course of even such mighty rivers as the Mississipi and the Orinoco; that to such small objects are due the successive bifurcations of their channels; and these changes, therefore, should be to us the most encouraging of examples to induce us to rely upon being able, by well directed efforts, to make obedient to them the course of any river.

These alterations are seldom required except through alluvial formation, and here the action of the current will readily effect what is required. Towns, which in olden times have been injudiciously placed as regards their position on the banks of rivers, or when the existence of great depth of water was not requisite for the trade in the remote period of their construction, may have those advantages brought to them, and that, too, frequently with at but little cost, as regards the establishment of works to give a new change to the course of the stream.

CHAPTER XI.

ON THE PHENOMENON ATTENDANT UPON MANY TIDAL RIVERS CALLED THE BORE, AND IN OTHERS THE ROLLERS, THE POROROCA, AND THE MASCARET.

THIS subject has been treated at a great length by Col. Emy, in his work "Du Mouvement des Ondes," in which he tells us, that "in the Dordogne the phenomenon bears the name of the 'Mascaret,' and is a peculiar undulation which announces the arrival of high water." In the Amazon it is called the Rollers, the Indians naming it the Pororoca. In the Hoogly it is named the Bore, by which term it is also known in the Severn, and on the river formed by the reunion of the Tigris and the Euphrates. In the Seine it is called the Bar.

The mascaret of the Dordogne consists of two, three, and sometimes four lofty waves, which follow each other rapidly, damming back the whole breadth of the river, and ascending the channel for a great length, often breaking at their crests and overthrowing every obstacle that they meet. Their presence is also made known by a terrible noise. Those of the Dordogne, which are the most remarkable in Europe, attain only an elevation of from 5 to 6 feet.

The mascaret of the Dordogne traverses about two leagues of the channel of the river from St. Pardon à Libourne in 33 or 34 minutes.

This subject was also one which excited greatly the attention of Condamine, while on his voyage down the Amazon, in reference to which he gives the following account in his work, at page 193. "Between Macapa and North Cape, in the place where the great channel of the river is contracted by the islands, and particularly opposite the mouth of the Arawary, which enters the Amazon on its northern shore, the flux and reflux of the sea presents a singular phenomenon.

"During the three days nearest the full and change of the moon, the period of the highest tides, the sea, in place of taking six hours to arrive at its height, attains the latter in two or three minutes.

"We may conceive that this cannot come to pass tranquilly, we hear at a distance of one or two leagues, a terrible noise which announces the approach of the *pororoca.* This is the name which the Indians of these parts give to this impetuous wave. As it approaches the noise increases, and we then see a promontory of water of from 12 to 15 feet in height, then another, then a third, and sometimes a fourth, which following each other closely, occupy the whole breadth of the channel. This wave advances with a prodigious rapidity, breaking up and sweeping away every obstacle from before it. I have seen in some situations a great mass of land borne before it, majestic trees rooted up, destruction of all kinds. Every where that it has passed, the shore is clean as if it had been swept with care. The canoes, the Indian boats, even ships have no other means to guarantee themselves from the fury of this *barre*, (the French name by which it is called in Cayenne,) except in mooring in a situation where there is a great depth of water. I will not here enter into a greater detail of the fact, nor of its description; I will but indicate the cause by stating, that, after having examined it with attention in many places, I find *the phenomenon only occurs when the wave ascending in a narrow channel meets in its passage with a bank of sand or elevated bed, which becomes an obstacle to its passage; that it was there, and no where else, where this impetuous and irregular movement of the waters commenced, and that it ceased a little above the bank, where the channel became again deep or widened considerably.*"

The most recent notice of this interesting subject is in the report of the Committee on Waves, appointed by the British Association in 1836, in which the Committee have adopted the views of Bremontier. I will, however, first refer to the report by Sir

John Robinson and John Scott Russell, Esq., for their description of the bore.

"17. *A tidal bore is formed when the water is so shallow at low water, that the first waves of flood tide move with a velocity so much less than that due to the succeeding part of the tidal wave, as to be overtaken by succeeding waves, or whenever the tide rises so rapidly, and the water on the shore or in the river is so shallow, that the height of the first wave of the tide is greater than the depth of the fluid at that place.* Hence in deep water vessels are safe from the waves of rivers which injure them on the shore."

In Emy's work, "Du Mouvement des Ondes," is the following: "*Bremontier has supposed that the tide rises by little beds flowing one over the other, and that by the effect of the velocity of the superior ones, they arrive at the same time at a point where their reunion forms the mascaret or bore.*"

"Others are satisfied with considering this phenomenon as due to the current of the flood, which, long retarded by the waters of the ebb, acquires at last a superior strength, and precipitates itself forward with great velocity, driving before it the waters of the river." The opinion last alluded to is that of M. G. Bidone, who has sought to explain the phenomenon of the bore by his theory on eddies; but this is not considered satisfactory by Col. Emy, because he says it does not account for the elevated waves which advance before the flowing tide.

The theory by Bremontier does not offer a satisfactory solution of the cause of the phenomenon, because, though we may admit that there is a great inequality in the velocity of the tide during the time it takes to attain its maximum elevation, still the effect of that accelerated motion of the tide can only be to impart a portion of it to the mass of water which had preceded it.

We may safely state that *in all rivers* "the first waves of flood tide move with a velocity much less, than that due to the succeeding part of the tidal wave," and yet as the formation of the bore is but an exception to the state in which we find rivers, we must look to other causes to solve the difficulty. We shall not find it in Colonel Emy's theory, which assigns it to his "flots du fond," as they could not possibly be found except in stormy weather, and the bore is visible alike in calms as in tempests, and is independent of the latter, except so far as they influence the height of the tides.

There appears to be a general agreement, that the presence of the bore is most strongly evinced as it passes over a portion of the channel which is encumbered with a sand bank.

Condamine and Bidone have partly arrived at the cause, so far as their views are stated in the foregoing pages, where they attribute the bore to the sudden influx of the waters of the tide, after having attained sufficient head to overcome those of the ebb.

If to the above we include the presence of an abrupt contraction of the width of the channel, this latter circumstance, taken in conjunction with any obstacles in the bed, such as the sand banks noticed by Condamine, will, in my humble opinion, be sufficient to account for the formation of the bore.

The examples of the bore of the Severn, and the mascaret of the Dordogne, are precisely similar; in both rivers we see the effect of a gradually contracted channel producing a great increased rise of tide; and we find the phenomenon alluded to occurs where the passage of that augmented tidal wave is checked by the presence of sand banks, and a sudden change in the configuration of the channel; or by the latter becoming violently contracted.

Thus the Severn experiences a rapid contraction at the islands of Flatholme and Steepholme, and also at Beachley near the mouth of the Wye.

During spring tides the rise at St. Ives in Cornwall is eighteen feet, at Padstow twenty-four, at Lundy island thirty, at Minehead thirty-six feet, at Kingsroad near the entrance of the Avon forty-eight feet, and at the entrance of the Wye fifty feet.

At this distance the tidal wave attains an elevation of thirty-two feet above that at the entrance of the Severn or Bristol channel.

Higher up the Severn, beyond the confluence of the Wye, where the elevation of the tidal wave is thirty-two feet above its level at sea, the channel becomes much obstructed by rocks and sand banks, which have the effect of rapidly elevating its bed. Fifteen miles above the mouth of the Wye, the Severn takes an abrupt turn in its course, forming an angle of nearly sixty-six degrees with its previous direction. This and several other similar obstructions to the passage of the tidal wave so affect it, that we find that at Gloucester the rise of tide is only about eight feet; the whole of which arrives at its full height in a few minutes, coming up in a bore, having a crest or face of from four to five feet. At 18½ miles above Gloucester, (where a weir or dam has lately been proposed to be constructed across the Severn,) the flow is only two feet, and at this place we find, from the excellent longitudinal section of the Severn by Mr. Rhodes, that the level of high water is lower by 2 feet 2 inches than at Gloucester.

At twenty-two miles above Gloucester, the Severn loses its character of a tidal river, *but it is well worthy of remark, that at this place the summer level of the surface of the Severn is about 3 feet 6 inches below the level of high water spring tides at Gloucester; where a great depression of the tidal wave already exists.* A very little reflection must draw our minds to the conclusion, that it would not be difficult to obtain a tidal navigation to Worcester, for sea borne vessels.

In the Severn, we notice that the progress of the tidal wave in the lower division of its channel is attended with a gradual increase of elevation or flow, and that, owing to the subsequent obstructions, arising from the circuitous nature of the course of the river in its upper tidal division, as well as from the impediments in its bed, the tidal wave is unable to continue its transit, even at the level already attained, and experiences a gradual depression.

It is in this latter portion of the course of the Severn, that the presence of the bore is most apparent.

The effect which the configuration of coasts has upon the tide assists to point out the fact, that to precisely similar causes must be attributed the increased flow observable in the Severn, but with the addition that the latter must be augmented, inasmuch as the influences of two shores are impressed upon the tidal wave.

We know that while a strong downward current is maintained, the progress of the early portion of the tidal wave must be along the shores, where it meets with least resistance. If a transverse section be made of the surface of the river, to show the central or descending current, and the lateral or ascending tidal wave which is divided by the former, the lateral currents or portions of the tidal wave will be found at a higher level than the surface of the central current, which continues its downward course. The difference of level is equalized by the extra rapidity of the latter, an eddy dividing the otherwise opposing currents.

Any sudden contraction of the width of the channel, or any elevation of the bed by the presence of a sand bank, must immediately have the effect of bringing into collision these opposite moving masses of water, and the crested wave or bore becomes apparent. Condamine tells us that "the bore becomes visible in passing over a shoal, and that it subsides again where the water becomes deep;" and we know also that the bore is at one time visible in the centre, and at another on the sides of the river.

Thus, in the early portion of the flood tide, when the waters of the river still run ebb in mid channel, the effect of the presence of a shoal, or high bank of sand, would be to divert the current towards the shores of the river, and thus still further elevate the lateral tidal currents, which, on attaining this additional height, must spread from shore to shore, and form the breaking wave, or bore, visible upon the sand bank, over which it will range in the manner described by Condamine, bearing before it in its course the whole mass of the previous ebbing waters, with which it has now come into complete opposition.

The river Dordogne unites with the Gironde, about forty miles from the embouchure of the latter, at which distance the Garonne is also received into the Gironde. The "mascaret," as the bore is locally termed in the Dordogne, is not apparent either in its sister stream the Garonne, or in their majestic recipient the Gironde, by which name the subsequent course of the Dordogne and Garonne is known after their union.

The velocity of the mascaret of the Dordogne, when measured by Bremontier between St. Pardon and Libourne, was found to be seventeen feet per second. This is, however, much less than the mean velocity of the tidal wave from the mouth of the Gironde to Bordeaux, which averages nearly twenty-five feet per second.

From the same tidal observations by Bremontier, we learn that the oscillations of the tides in the beds of the Gironde and Garonne go up, as on an inclined plane, far above the level of high water at the embouchure of the Gironde: that at La Reole, thirty-four miles south-east of Bordeaux, the tide appears to flow ten toises (fathoms), and at Bordeaux, five toises above the low water mark, near St. Pierre de Royan, at the mouth of the Gironde; yet the flow of the tides are the same in height at Royan and at Bordeaux, viz. about two fathoms. This gives a rise of three fathoms of the high water surface at Bordeaux, above that of the same tide at sea.

The full force of the tide is directed up the Dordogne, in consequence of the mouth of the Garonne being sheltered by a succession of islands situated on the south side of the Gironde, the northern shore of which is alone clear of such obstructions.

The great distance of the Dordogne, from the embouchure of its recipient the Gironde, at once disproves the theory advanced by Colonel Emy, that the bore is formed by the ground waves described in his work.

APPENDIX.

REPORT

OF THE IMPROVEMENTS IN THE RIVER CLYDE, BY W. A. BROOKS, C. ENGINEER, MADE BY ORDER OF THE TEES NAVIGATION COMPANY, IN 1833.

To the Committee of the Tees Navigation Company.

GENTLEMEN,

The inquiries to which my attention was directed in the investigation which I had the honour of making last month, in conjunction with a member of your Committee, (Mr. J. Cartwright,) relative to the alteration which has been effected in the navigation of the river Clyde, were naturally divided into the following heads:—

1st.—As to the state of the river Clyde, previous to any alteration having been made in it by art.

2nd.—The principle upon which any alteration which had been effected was based.

3rd.—The means used to carry the above principle into effect.

4th.—The result of those means or works of art upon the navigation of the river.

5th.—Whether the alterations were such as to give additional facilities to the commerce of Glasgow and the surrounding country, or the reverse.

6th.—To ascertain whether in the improvement of the navigation of the Clyde any means, or works of art, had been adopted, which might be likewise beneficially made use of in the completion of the improvement of the navigation of the Tees.

7th.—Whether from the experience which has been gained in carrying on the aforesaid alterations, any of the errors which so frequently are found to increase the cost of public works may be avoided in the execution of those undertaken by the Tees Navigation Company.

1. With regard to the state of the navigation of the Clyde previous to the commencement of the works for its improvement, no evidence can be clearer than that given in the Reports to the Magistrates and Council of Glasgow, by—

Mr. James Smeaton, C. E. of the 3rd of Sept. 1755,
Mr. John Golborne, C. E. of the 20th of Nov. 1768,
Mr. James Watt, C. E. of the 20th of Oct. 1769,

which all prove, that the navigation of the river, as well as the flow of the tide, was so much obstructed by bars or sand banks, that barges, or similar craft, drawing about three feet of water, could alone be made use of for the trade of the important city of Glasgow, whereby a greatly increased expense was imposed upon it by the transportation of its manufactures to be shipped at ports which did not labour under similar defects, viz. Port Glasgow and Greenock.

To the Reports alluded to above, copies of which will be found in the accompanying book and portfolio of plans of the Clyde, I beg to refer, and particularly to call your attention to the observation made by Mr. Smeaton, "that the rise of tide at spring tides on the Hirst Sand (a shoal so called, situated a little below the city of Glasgow) was only 1 *foot* 9 *inches*, and that the *total depth* over the same, at *high water spring tides*, was but 3 *feet* 3 *inches*. At Point House Ford, (two miles below Glasgow,) the depth was only 1 *foot* 6 *inches* at low water, and the flow was 2 *feet* 2 *inches*, making a *total depth of* 3 *feet* 8 *inches*. At Marlinford, $3\frac{3}{4}$ miles below Glasgow, the depth on the shoal there was also 1 *foot* 6 *inches*, which, with the flow of 3 *feet* 3 *inches*, gave 4 *feet* 9 *inches*, *at spring tides*. At Blarthill Shoal, there was *about the same depth*; and at Speydock Ford, near Stocktown, the depth at low water was also 1 *foot* 6 *inches,* and the flow, 4 *feet* 6 *inches, at spring tides.*

The fourteenth statement in Mr. Smeaton's Report, is, " that the navigation is free at ordinary neap tides, as far up as Speydock Shoal, for vessels that do not draw above 4 feet 6 inches water." And that gentleman proceeds in his report to recommend the construction of a dam or weir across the river at Marlinford, to raise the level of the river between the latter place and Glasgow, or to enable the intervening space to be navigated by vessels of the above draught of water; a barge lock being to be introduced in the proposed dam at Marlinford, for the purpose. Thus converting the tidal navigation above Marlinford into a still water navigation for small craft.

It appears that the public deemed even that measure more desirable than the navigation of the river in its state at that period, and an act of parliament was obtained with full powers to carry the above project into effect. Happily, however, for the commercial interests of Glasgow, a different view of the capabilities of the river for being improved, was taken by Mr. J. Golborne, C. E., who, on being consulted by the Commissioners, made the Report to them of the 30th of November, 1768, a copy of which is marked No. 2, in the accompanying book. Upon the views contained in that Report, it appears that the Commissioners of the river Clyde have acted with great success.

That Report is particularly worthy of your attention, and I am satisfied that you will immediately perceive the great similarity between the Tees and the Clyde, previous to the commencement of your works; as also, that the latter have brought about the same result, anticipated by Mr. Golborne, as the effect of the works recommended by him for the improvement of the Clyde. I particularly allude to the increased flow at Stockton, occasioned by the reduction of the low water level, as stated in a Report by me, which was read at your last general meeting.

It will be shown in this report, that the subsidence of the Clyde at Glasgow, at low water, has taken place to a still greater extent than in the Tees, and that we have in the Clyde an encouraging practical example, which strongly demonstrates that the difference of the flow of the tide between Stockton and Cargofleet, will become still less than at present, although that difference is already less by one half of what it formerly was.

Previous to the commencement of the contraction of the width of the river by the jetties recommended by Mr. J. Golborne, the celebrated James Watt, C. E., was appointed to report upon the state of the river, particularly as to the longitudinal section of its bed from Glasgow to Dumbuck Ford; a copy of which is marked No. 3. The depth of water on the shoals appears in his examination to have been very similar to those ascertained by Messrs Smeaton and Golborne, but his levellings prove that the observations made by Mr. Smeaton as to the declivity of the river at low water must have been incorrect. Thus, at Dumbuck Ford alone, there was found to be "*a fall of* 10 *inches in a length of* 750 *yards*," in lieu of "*the declivity of the river at low water being very gentle, even upon the shoals, and almost stagnant upon the deeps*," according to Mr. Smeaton's inspection.

The low water level at Dumbuck Ford (as ascertained by Mr. James Watt,) was 5 feet 1 inch below the low water at Glasgow, or a fall of about 5 feet 1 inch, in a length of about ten miles and a half. The difference of level between the low water at Cargofleet, and the low water at Stockton, a course of seven miles, previous to the commencement of the works, executed under my superintendence in the Tees, was very similar to the above.

From the account of the river by Mr. Watt, it is clear that had Mr. Smeaton taken the same pains by levelling to ascertain its state, the views of that talented man, as to the capabilities of the river, would have been of a more extensive nature, or in accordance with those which were subsequently adopted by Messrs. Golborne, Rennie, and Telford.

I have now, previous to closing my remarks upon Mr. Watt's report, to notice an observation made by the latter gentleman upon Mr. Smeaton's Report, as follows:—

"*It appears from Mr. Smeaton's observations and levels, that the tide in the upper part of the river rises above the true level, particularly after it passes the Pointhouse.*"

On the above I have to state, that the levels given in Mr. Smeaton's Report *do not* warrant the above remark, the tide being found by Mr. Smeaton to diminish gradually in amount of flow as it ascended the river, in exact proportion to the difference of level of the low water line at the several places of observation recorded.

Thus, the top of the shoal at Pointhouse was five inches below the top of the Hirst Shoal, which difference, added to the depth at low water of 1 foot 6 inches, and flow of 1 foot 9 inches at the latter place, is exactly equal to the depth at low water of 1 foot 6 inches, added to the flow of 2 feet 2 inches at the former shoal.

Again, Dumbuck Ford was found to be 5 feet 1 inch below the Hirst; which amount, added to the depth of 3 feet 3 inches on the latter shoal at high water spring tides, is also exactly equal to the depth observed on Dumbuck Shoal; thus proving that the tide rose to the same level at high water throughout its course.

The observations and levels by Mr. Kyle, taken in 1824, also prove that the tide rose at that time to the same level at all the places observed by him between Glasgow and Port Glasgow, a distance of 18½ miles.

It appears from the foregoing Reports noticed by me, that the rise of tide at Glasgow, as observed by Mr. Smeaton, was only 1 foot 9 inches; and the ordinary flow at Port Glasgow, situated 18½ miles nearer the sea, being 11 feet, the difference between those two places was 9 feet 3 inches in favour of the latter, which probably caused the establishment of that harbour in the frith or estuary of the Clyde; but owing to the contraction of the width of the river by jetties, and thereby procuring the removal of the shoals which dammed up the surface of the river at low water, and prevented the free admission of the tidal water, I find, as per annexed tide table, and by the observations of the harbour master at Glasgow (Capt. Johnstone), and other parties who have given much attention to the subject, that the present rise of tide at spring tides at Glasgow averages 8 feet 6 inches, and that the difference of flow between Port Glasgow and Glasgow is therefore only 2 feet 6 inches, in lieu of 9 feet 3 inches, as in 1755.

The increased flow at Glasgow (or over the old site of the Hirst Shoal) is therefore 6 feet 9 inches, which, added to the difference between the present and former available depths at low water, gives the total amount of the improvement effected in the navigation of the river Clyde.

By the soundings taken by Mr. Smeaton in 1755, the depth on several of the shoals was only 1 foot 6 inches, which was also the depth on the Hirst.

In 1768, Mr. Golborne recorded the depth on the same shoal, as only amounting to 12 inches.

In 1769, Mr. James Watt found the depth over the same shoal to amount to 1 foot 2 inches.

Taking Mr. James Watt's observation (it being nearly a mean of the three) and subtracting it from the present available depth at low water of 5 feet 6 inches, we have 4 feet 4 inches as the increased depth at low water, which, together with the additional flow alluded to, of 6 feet 9 inches, *makes the total improvement in depth at high water spring tides in the navigation of the river up to the city of Glasgow, to amount to* 11 *feet* 1 *inch.*

I have stated that the increased flow at Glasgow is found to amount to 6 feet 9 inches; and as the works for the improvement of the Clyde have not extended below Dumbuck Ford, between which place and Glasgow the difference of level at low water formerly amounted only to 5 feet 1 inch, it follows that the increased body of tidal water, which since the improvements were commenced flows up the river, has had the effect of deepening the channel below, and thereby causing an additional flow of tide between Dumbuck and Port Glasgow.

The following extracts made by me from the journal kept by the harbour-master of Glasgow (Capt.

Johnstone) of all vessels of above 11 feet draught of water which have navigated the Clyde up to the Broomielaw quay at Glasgow during this year will, I have no doubt, be considered to be indisputable proofs of the great improvement which has taken place in the river Clyde.

Account of the Arrival at Glasgow of all those Vessels which have exceeded in draught eleven feet, in the year 1833; extracted from the Harbour-master's Journal.

Date of Arrival.		Name of Ship.	Master.	Particulars.	Registered Tonnage.	Draught of Water.
1833.				From		
Jan.	5	The Sutors	J. Donaldson	Limerick	..	12 ft.
—	10	The Herefordshire	T. Londey	Newport	..	11 ft. 6 in.
—	22	The Union	D. Cunningham	Clare	..	12 ft. 3 in.
—	23	The Eliza	J. M'Keddie	Gloucester	..	11 ft. 6 in.
—	24	Rose	J. Strang	Westport	..	12 ft.
—	25	Margaret	..	..	..	11 ft. 6 in.
Feb.	4	The Love	Glaves	Libata	153	14 ft. 6 in.
—	6	Bulwark	..	..	..	11 ft. 6 in.
—	25	Tiger	..	..	..	11 ft. 6 in.
—	27	William and Ann	..	Toreste	..	12 ft.
March	6	Nancy	J. Wilson	Limerick	158	12 ft. 6 in.
—	21	Swan	J. Little	..	..	11 ft. 9 in.
—	25	Ant	Webster	Sligo	142	12 ft.
April	5	Arcturus	..	Limerick	147	13 ft. 3 in.
—	6	Janet	..	..	..	11 ft. 6 in.
—	8	Union	..	Limerick	..	12 ft. 3 in.
—	11	Helen	..	..	133	11 ft. 6 in.
—	11	Planter	..	Marseilles	160	13 ft.
—	19	T. Carroll	..	Limerick	143	13 ft.
—	20	Diana	..	..	..	12 ft.
—	29	Lady Amherst	..	Marseilles	130	12 ft. 6 in.
May	21	Aurora	..	..	..	11 ft. 6 in.
June	3	Martha	..	..	..	11 ft. 3 in.
—	17	Supply	..	Odessa	..	12 ft.
—	22	Waterloo	..	..	..	11 ft. 3 in.
—	26	Union *	..	Sicily	..	12 ft. 6 in.
July	16	Bruxton *	..	St. Domingo	..	12 ft. 6 in.
Aug.	10	Duch. of Portland *	..	Archangel	173	12 ft. 6 in.
—	12	Catherine *	..	Londonderry	168	12 ft. 3 in.
—	15	Albion *	..	Montreal	190	13 ft.
—	20	Gratitude *	..	Tynemouth	..	12 ft.
—	20	Ann *	..	Limerick	144	12 ft. 6 in.

NOTE. Those vessels marked with stars were in the Clyde when the state of the River was examined by W. A. Brooks, C. E. by order of the Tees Navigation Company, and it is also to be observed, that many of the vessels in the above list arrived during neap tides.

The principle, upon which the Trustees of the River Clyde have acted for the removal of its numerous shoals, having been thus ascertained to be the production of a temporary increased velocity of the tides to deepen the bed of the river, effected by the contraction of its width, I have now to describe the works which have been constructed at different periods for that purpose.

In the Report by Mr. Smeaton in 1755, that gentleman recommended the adoption of this principle for the removal of Blarthill Shoal below the dam proposed by him at Marlinford, and he further describes the jetties to be made of two rows of piles and wattling, the interval being filled up with stones." In one of my visits for the purpose of examining the works I noticed the remains of one of the above described construction.

The plan generally followed has been to make the jetties of grass sods faced with rubble stones, where not much exposed to the current, and of a solid pyramidical bank of stones towards their extremities. They were raised only to the level of ordinary tides; and it will be readily apparent, that a reason for this want of height was the increased expense which would have been incurred, by forming them of a sufficient height to prevent their being surmounted by the great floods which occasionally happen in the Clyde; an object which is however easily and cheaply effected, when timber jetties are used, on which the increased quantity of material is nearly in direct proportion to the difference of height between the high and low jetty, but which is far different where the sectional area of the jetty must be at least as the square of its height, which is the case where the clay and stone jetties are used, as in the Clyde.

The progress of the improvement of the river appears to have been very much checked by the jetties not having been formed of sufficient height to prevent the floods or "speats" passing over them, which invariably in their fall over the jetties appear to have carried away the deposit below these jetties, brought by smaller tides and freshes; an uniform silting up of the spaces being thus prevented.

The accompanying tracings of a survey of the river in 1806, made by the advice of the late Mr. John Rennie, clearly shows that the effect is produced by this defect in the formation of the jetties.

Mr. Golborne, in his last Report, which is dated Sept. 7, 1781, recommended those jetties being raised; and had his advice been followed, all that was requisite would have been effected to secure an uniformity of level in the deposit between the jetties, and its consequent attendant effect—regularity of depth of water in the channel; and the trading interests of Glasgow would have been saved the burthen entailed by the construction of the expensive parallel stone dykes which have since been made.

When the late Mr. J. Rennie surveyed the river in 1807, and reported thereon on the 24th Dec. in that year, he stated in this Report that "*the difference in depth of the section of the river opposite the jetties and between them was from* 9 *to* 12 *inches.*" A small difference indeed in comparison to the total increase of navigable depth, which up to that time had been made without the construction of the expensive parallel dykes, or connecting rubble quay work; and also when due regard is paid to the length of time requisite to complete an uniform deposit between the jetties.

The above variation of from 9 to 12 inches, may be fairly attributed to the want of height in the jetties, which if raised as recommended by Mr. Golborne in 1781, would, in my opinion, have left *very* little difference to be found by the examinations of succeeding engineers.

The jetties in the upper division of the river have been made to point very much down stream, and an unnecessary expense has been thereby occasioned. This defect is not, however, conspicuous to so great an extent in those jetties which have been more recently made.

In the report by Mr. T. Telford, of the 24th May, 1806, as well as in that by the late Mr. Rennie, in Jan. 1807, those gentlemen recommended a continuance of the parallel stone dykes, which had been about that period constructed by the trustees in some parts of the course of the river. They were judiciously recommended to be raised only to the level of half-tide, which plan, if acted upon, would have permitted a considerable portion of the sand, &c. moved by the freshes and tides to deposit itself between the jetties. The parallel dykes have, however, been generally raised to the level of high water spring tides, and consequently pools of stagnant water are to be met with on the west side of the jetties, wherever those pools (or deep holes before described as being made by the overfall of the freshes) have not been filled up with materials raised by dredging vessels and wheeled over the parallel dykes.

The parallel dykes are all formed of rubble whin stones, which cost 1*s.* 9*d.* per ton, delivered into the work. The superintendant of the works, Mr. Clarke, told me that a very large proportion of the said parallel dykes were made in 10 feet water at low water.

The extracts made from the surveys and soundings by Mr. Kyle, of Glasgow, which I have copied into the accompanying book, are highly interesting. I have already observed that that gentleman proved, by his levellings in 1824, that the tide rises in the Clyde to the same level throughout its whole course between Port Glasgow and Glasgow, a distance of 18½ miles; and his lines of soundings, taken at every quarter of a mile in that space, prove that no bar has been deposited by the alterations which have been effected.

About the period of the survey by Mr. Kyle, a communication was made to Mr. Whitbey, of Plymouth, (viz. on the 1st Sept. 1824,) requesting his opinion as to the best means of still further improving the navigation, to which, after visiting the works, a formal Report was sent in reply, "recommending the Trustees to remove all the works they had executed, and to endeavour to restore the river to its ancient state." I have copied the application to Mr. Whitbey and his reply in full, in which the latter gentleman has evidently been more intent upon preserving the salmon fishery of the Clyde, and adapting it for its convenience, than for the great commercial interests of the important city of Glasgow. Mr. Whitbey makes a special statement, that "the salmon fishery will be thereby preserved." The Trustees of the Clyde appear, however, not to have been satisfied with the improvement of the salmon fishery, as a sufficient reason for giving up the advantages they had so long derived from the improvement of the navigation of the Clyde, which they continued to steadily persevere to complete, according to the recommendations of Thos. Telford, Esq., C.E.; and the result at this period is as proved by the list of the arrivals of vessels of large draught of water which I have given, some of the largest of which arrived at Glasgow during neap tides, or the Clyde is navigable at this time for vessels drawing 14 feet 6 inches in lieu of only 3 feet. The greatly increased vertical flow of tide at once disproves the rest of Mr. Whitbey's conjectures.

I have the honour to be, Gentlemen,

Your most obedient Servant,

W. A. Brooks, C.E.

Tees Navigation Office,
7th Sept 1833.

THE END.

Gilbert & Rivington, Printers, St. John's Square, London.