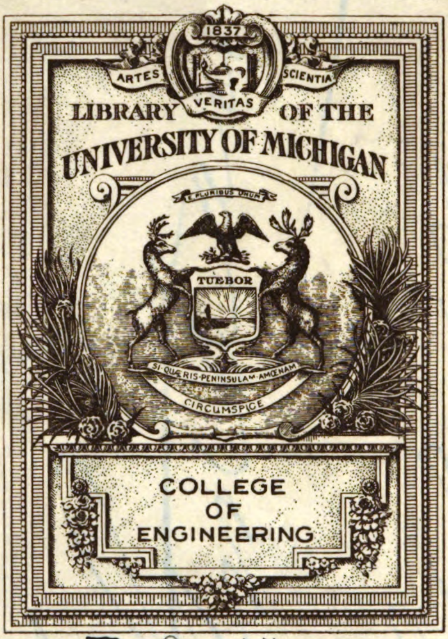
CALVER
ON THE
IMPROVEMENT
OF
TIDAL RIVERS



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THE

CONSERVATION AND IMPROVEMENT

OF

TIDAL RIVERS,

CONSIDERED PRINCIPALLY WITH REFERENCE TO THEIR TIDAL AND FLUVIAL POWERS.

BY

EDWARD KILLWICK CALVER, R.N.,

ADMIRALTY SURVEYOR.

> "In the search after Truth, it is better to take hold of broad and established facts, than to be perplexed among the depths and difficulties of those things which are theoretical and empirical."
> * * * * * * * *

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TO

CAPTAIN WASHINGTON, R.N., F.R.S.,

THIS BRIEF TREATISE

UPON A SUBJECT OF INCREASING IMPORTANCE,

AND ONE WHICH IS SO GREATLY INDEBTED TO HIS SEARCHING INVESTIGATIONS
AND UNTIRING LABOURS,

IS BY PERMISSION INSCRIBED

BY HIS OBLIGED SERVANT,

E. K. CALVER.

PREFACE.

A few prefatory remarks only are necessary to explain the origin of the present work, and the plan on which it is constructed.

The writer has been employed for many years in the Hydrographic branch of the Naval Service, and has been engaged upon Surveys of most of the Ports between the North of Scotland and the River Thames. Without having any preconceived notions of his own upon the subject, he has carefully observed the distinctive features of the several Harbours, — the works which have been adopted for their improvement, with the measure of success attending them,—and he has not failed to perceive (what indeed will be generally admitted), that owing apparently to the absence of a well-digested code for general guidance, Hydraulic Engineering, as applied to marine works, has not kept pace with the other branches of practical science.

The writer cannot supply this desideratum, nor does he propound any new theory; but as an extensive field of observation has enabled him to form general views upon the subject, and a late work of examination in which he was engaged having satisfied him of their soundness, and given them consistency, he commits them to the press, as his mite of information, where so much is needed. The small amount of leisure at the writer's disposal precluded his attempting more than a brief explanation of certain examples, and the lessons they convey; but, with his views of usefulness, he felt he could not do less: for, as Professor Robison remarks, "It is not improbable but that, in the solutions which may be obtained of particular cases, circumstances may occur which are of a more general nature. These will be so many laws of Hydraulics to be added to our present very scanty stock; and these may have points of resemblance, which will give birth to laws of still greater generality." The intention of the act will disarm criticism; and if it be the means only of inducing others to detail their experience, a grain of truth may be culled here and there, and something definite, intelligible, and authoritative may at length be evolved out of the mists and mazes with which the subject is still surrounded.

One leading point has been kept constantly in view in this Treatise, viz., that at the present time, when the laws of Hydro-dynamics are only sketched out rather than filled up, practical examples are the safest finger-posts on the road to Truth, for Nature will answer faithfully if we interrogate her,—*not if we interrogate ourselves.* These pages, embodying the experience of seventeen years, are only offered as a reasonable discussion of points of major importance, and upon which opinion is still much divided. An extensive sphere of observation has been mentioned as the writer's warrant for treating upon the subject, and more than a passing reference might also be made to those instances where his opinions have received the sanction of experience, were the subject not personal, and the act therefore liable to be misconstrued. Many of the views are peculiar, but they are not urged in any spirit of hardy dogmatism: if they are sound, they will be useful; if otherwise, they will do no harm, and will soon be forgotten.

As the work is particularly addressed to unprofessional readers, all unnecessary technicality, all cumbrous formulæ, and all theory not strictly applicable to the case, have been carefully avoided. Executed as a winter-evening recreation, only the more important points have been touched upon; and, keeping in view the practical end proposed, the aim has been, to give more attention to the logic of facts than to the rigid fitness of a word, or to the construction of a sentence. Incompleteness must needs be a prominent feature of such a work, but it is trusted it will not be found unaccompanied in this instance with materials for thinking. The deep interest the writer takes in the subject for its own sake, may, however, have betrayed him into indiscretion, and the reader's indulgence is therefore requested for any undue earnestness of expression in this well-meant attempt to treat a 'vexed question.'

Sunderland, May 10th, 1853.

CONTENTS.

CHAPTER I.

CHAPTER II.

THEORIES.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CONSERVATION AND IMPROVEMENT OF TIDAL RIVERS.

CHAPTER I.

INTRODUCTORY — RIVERS, FRESH-WATER AND TIDAL — FEATURES COMMON TO BOTH — THEIR RESPECTIVE POWERS — DIFFERENCE OF EXISTING OPINION AS TO THEIR RELATIVE IMPORTANCE — THE CAPACITY OF THE OUTLETS OF TIDAL RIVERS CAN ONLY BE MAINTAINED BY STRICT CONSERVATION OF THE TIDAL QUANTITY — THE DOCTRINE SUPPORTED BY PROFESSIONAL OPINIONS AND WELL-KNOWN CASES OF HARBOUR DECAY.

INSTEAD of taking a wide range of illustration in the following Treatise, we propose to confine our attention to the rivers dividing the surface of our own country, a class humble in extent and natural power, and which, compared even with those that issue from the adjacent continent, are only to be regarded as narrow creeks or inlets, kept open by the joint action of the fresh-water streams and the tide.

"The term *river*," says Professor Robison, "is appropriated to a considerable collection of waters, formed by the conflux of two or more *brooks*, which deliver into its channel the united streams of several *rivulets*, which have collected the supplies of many *rills*, trickling down from numberless *springs*, and the *torrents* which carry off from the sloping grounds the surplus of every shower."

There is truly much to interest and instruct in the constant interchange between the earth and its atmospheric covering, and the economy and mechanism of running waters to which it gives rise; but the doctrine of fluids, or the laws which govern running streams, in so far as they have been clearly ascertained, will occur more properly in subsequent divisions of this Treatise, our remarks at present being limited to a brief description of rivers, with their principal features and powers.

Such are the variations produced by local causes, that any attempt at classification of rivers would be both difficult and useless: it is quite sufficient for our purpose to state that a river in its descent from the high grounds to a lower level is to be considered as a succession of inclined planes, gradually decreasing in slope as they approach the sea. Gravity, the sole cause of motion in running-streams, is constituted a moving power by the slope of their surfaces, while the rate of the current is regulated by the friction of the bed acting upon the viscidity of the molecules of water. The river, confined at first in the valleys of its upper course, and impelled forward by the steep descent along the line of least resistance to which it adheres, often assumes the form of a succession of rapids and pools, or, as they are properly termed to betoken their effect, falls and counter-falls: were it not for this provision, and others of a kindred nature, no soil could resist the impetuosity of the stream, and the accelerating force would render it a curse rather than a blessing. As it continues its course, and receives the addition of affluents from either side, its volume is increased, its bed is widened and deepened, and the velocity further modified, till at last it arrives at a point where its surface is on a level, or thereabouts, with high water of the sea; it then loses its distinctive character, and becomes merged in the tidal river. This sketch, allowing for the modifications due to the nature of the country from whence they issue, will answer as a synoptical view of most of the streams which exist among us, for they have in general leading features of analogy or resemblance.

In the tidal river, which exhibits the phenomenon of an alternating reversed current, the slope of the surface is reduced, and the motions are more equable. If the country be elevated, the river will be confined between steep banks, in a channel proportioned to the united volumes, salt and fresh, to its junction with the sea: if, on the contrary, the solid slopes of the country are retired, the course will be continued by serpentine meanderings. In some instances the river occupies at high water the whole space between the high grounds, and thus approaches the lagoon-shape. Generally speaking, the tidal river is of irregular width from filling the indents which are offered by the shores on either side, and thus its lower reaches not unfrequently assume the form of a wide estuary, only partially occupied at low water by the channel of the river, which, with many sinuosities, and crossing occasionally from side to side, finally joins its ultimate level, the sea.

The size of the two compartments of a river, fresh-water and tidal, depends in the former case upon the area of drainage, and upon the amount of the rain-fall to which it is a conductor; in the latter, upon its general capacity as a receiver, and the vertical lift of the tide upon the coast from whence it debouches. The entire length of the river from its source to its sea-outlet, including all its windings, is called its development.

The beds of streams from their source downwards are composed of different materials, coinciding with the geological structure of the country through which they pass. The wreckage caused by the detrital agent appears at first as large angular masses, but on descending the stream the size diminishes, for as the power of transport depends upon the slope, the detrital substances are carried further in proportion to their lightness: the smaller particles, from being subjected to attrition, are more rounded than the larger ones. Gravel ceases to travel when the slope is reduced on the average to 3 feet per mile, while the disintegrated particles of the softer sandstones, with the surface scourings of the ancient alluvial depositions, are carried forward to add to the mass of matter in the estuary.

The bed of the tidal river, from its position as to level, is the depository for a great portion of the minute detrital matter of whatever sort, arising from the degradation of the land in the surrounding district, and for a small quantity brought in from the sea-margin by the tide. The channel, which in the upper compartment is determined by the continuity of the downward current, is here subject to great fluctuations in its position and shape,—a character common to the generality of tidal rivers. In these, the changes both in the direction and width of the channel are of constant occurrence, and result at times from causes difficult to detect or specify; but they appear to be due principally to the ever-varying action of the flood and ebb tides during springs and neaps upon a bottom of soft and yielding material; to the disturbance of the ordinary arrangement by an occasional fresh, or to the deflecting effect of a nucleus or obstruction, causing the current to act upon its marginal banks, and, by the abrasion, to add to the moveable mass of soil in the basin. The effect of all these influences upon the channel in a navigable point of view, will form the subject of future remark, and accordingly we do not enlarge upon it here.

The comparative powers of the two streams, variable in themselves and with respect to each other, and more especially the real importance of the fresh-water stream in the tidal compartment with its ultimate effect upon the capacity of the bed, is a question of the highest moment, but one which has given rise to much difference of opinion and practice. A casual observer, upon noticing the feeble state of the fluent water during the greater portion of the year, and comparing the inferior sectional size of the bed of the river at the head of the estuary with that which it ultimately attains at the outlet, would consider the paramount importance of the tidal water in the tidal compartment an axiom to be admitted by every one; but such an admission is very far from being general, and the exceptions occur at times in the case of those whose opinions are entitled to consideration and respect.

It is not easy to overrate the importance of a clear understanding upon this point, for until some definite conclusion is arrived at, any projection of works for river amelioration is more like a leap in the dark, than the scientific adjustment of means to an end. We therefore propose in the first place to enter upon the inquiry as to whether a preponderating principle really does exist,—what that principle is, and afterwards to carry it to its practical issue. If this point be clearly understood, the ground for discussion will be considerably narrowed.

We begin by laying down a doctrine, and then bringing forward facts and reasoning in support of it. Our thesis is, that the navigable condition of the outlet of a tidal river can only be maintained by tidal water, and that its extent as to sectional capacity will be proportioned to the amount admitted.

In the following quotations from the opinions of Engineers of celebrity, past and present, and selected from those delivered in the maturity of their experience, care will be observed that expressions are not made to bear a sense which would not be fully borne out were the whole of the text given. The first is that of one of the "fathers of the profession," the illustrious Smeaton.

> "My opinion is in general, to discourage all attempts to prevent *the free influx and efflux of the tide and land waters, in order to preserve the channel out to sea* in the most effectual manner, upon which both the navigation and drainage dependent on the Ouse entirely hinge." — *Smeaton; Report on Lynn Harbour, 14th September*, 1767.

> "We consider the magnitude of every tide harbour, both as to width and depth, is generally proportionate to the quantity of such flowing and reflowing water; *and every subtraction from such quantity by embankment tends to decrease the magnitude of the outlet* to the harbour."—*Rennie and Jessop; Report on Rye Harbour, 24th February*, 1801.

> "The facts above stated (with reference to Scott's float sluice) are exceedingly satisfactory, *and clearly show the injury which is occasioned to harbours by the shutting of the tides out of their ancient channels, by embanking the marshes and mudlands over which they used to flow.*"—*Rennie; Report on Rye Harbour, 26th December*, 1812.

> "If the width of the river were to be contracted by a solid embankment, its depth would be increased, *but as a less quantity of tide water would thereby be admitted, it would have less effect in keeping down the bar.*"—*Rennie; Report on River Tyne, 17th June*, 1816.

"I have entered thus far into the nature of harbours similarly circumstanced to that of Great Yarmouth, for the purpose of showing *the advantage that arises from preserving to the utmost extent* that the nature of the case will admit *the receptacles into which the tide flows.*"—*Rennie; Report on Yarmouth Harbour, 29th May,* 1818.

"I am not aware that *any remedy can be substituted for the deprivation of backwater.*"—*Rennie; Report on Southwold Harbour, 6th January,* 1820.

"It is not to be forgotten, that as the sands and mud accumulate, and marsh lands are formed in the upper part of the estuary, *the power of scouring the lower portions* (*the entrance*) *is diminished.*"—*Telford; Report on River Dee, 30th April,* 1821.

"*If there were no receptacle for tidal water* to pass in and out at every tide, *the harbour would cease to exist.* The area of the entrance, as respects its width and depth, *is the balance* of the velocity and quantity of water which passes between the piers, on the one side; and the resistance, (bar and shingle,) on the other. If, with the same width between the piers, we reduce the quantity of water which has to pass in or out in the same time, we diminish at once the required velocity or power to remove obstructions, *and a decrease of depth follows almost immediately.*" And further on, "It is to be lamented that when the owners of estates were, perhaps, balancing in their minds whether the land they could reclaim would pay the expense of reclaiming it, they were not advised of *the injury they were about to do to the public and themselves by the reduction of the backwater upon which their harbour is dependent.*"—*Walker; Report on Southwold Harbour, 25th August,* 1841.

"The effect of *every erection between high and low water is to decrease the quantity of tidal or back water, upon which the depth* below the embankments *mainly depends.*"—*Walker; Report on River Thames, 13th December,* 1841.

"Liverpool, Yarmouth, Montrose, and many of our great harbours, *depend for their existence upon the tidal current,* and, therefore, the receptacle for tidal water ought to be preserved with jealous care."—*Walker; Report on River Tay, 21st January,* 1845.

"The tide in the roads is slow, but if the volume of water be materially diminished, so will be the velocity of the tide, and *consequently*, in the course of time, *the navigable channels or entrances to the river."—Walker; Report on Belfast Harbour, 6th March,* 1845.

"I consider the lower part, or the estuary, of the Clyde, *entirely due to tidal water.*"

"The object is the *greatest quantity of water, where the bar is to be removed by the effect of tidal water."—Walker; Evidence before Tidal Harbours' Commission, 11th July,* 1845.

"My deliberate opinion is, and my advice always has been, that it is improper to embank any land which is covered by neap tide, which water is necessary to keep open a harbour."

"Where you want a scouring power, or a tide to do good, and a harbour through which water passes on the flood, you should never embank any lands above that harbour which are covered by neap tide, because every cubic yard of water which goes in goes back again, and helps to keep the channel open."

"*Q.* Are the Commission to understand that enclosures, stopping the flow of tidal water, must gradually injure the bar of the harbour to which that formerly served as a scour?—*A. Yes, it will do so.*" —*Cubitt; Evidence before Tidal Harbours' Commission, 2nd July,* 1845.

(With reference to improvements in River Tay.) "If the tide is accelerated in time and height, it is accelerated beneficially for the harbour, *provided you have not reduced the quantity of water so as to affect injuriously the harbour's mouth,*"—"for this is benefiting the upper part of the harbour *to the injury of the lower part, or the bar."—Rendel; Evidence before Tidal Harbour Commissioners, 6th June,* 1845.

"On going carefully into the question of the *requisite quantity of backwater to scour and maintain the proper depth of water at the bar* and the lower reaches of the river, it became apparent that *the works which would least interfere with the capacity of the river as a tidal receptacle should be adopted."—Rendel; Report on Tyne, 11th October,* 1851.

"As the maintenance of the navigation *and the keeping down the bar depend mainly on the quantity of water passing over it,*

* * * * care should be taken that *no further embankments of the lands over which the tide is accustomed to flow be permitted.* * * * On the contrary, care should be taken to increase, either in width or depth, the space for the reception of tidal water."—*Sir John Rennie; Report on Wexford Harbour,* 31*st May,* 1831.

"This division of the river (the lower part) may be termed *the most influential, as regards the effects upon the bar;* as, in addition to the land or fresh water, *it forms a capacious receptacle for the tidal water.*"—*Sir John Rennie; Report on Warkworth Harbour,* 31*st March,* 1838.

"*All interruptions,* of whatever description, *to the free ingress and egress of tidal water, ought to be sedulously guarded against.*" —*Richardson; Report on Tyne,* 13*th July,* 1834.

"*Any encroachment on a tidal river or estuary,* by lessening the quantity of its backwater, *must diminish the scour at the lower parts of the river, and must thereby tend to form banks there, and so to injure the navigation.*"—*Leslie; Report upon encroachments in River Tay,* 22*nd September,* 1843.

"I think when you have an estuary *you should endeavour, if possible, to preserve it entire,* * * * *so that you may keep the great scour over the bar* at the mouth of it if possible."

(Respecting Tay.) "I think that any effect from a fresh at the bar *is a mere bagatelle compared with the scouring of tidal water.*"

"Q. Have you ever entertained opinions respecting encroachments of the river different from what you now entertain?—*A. No: I never have since I considered the matter at all.*"—*Leslie; Evidence before Tidal Harbours' Commission,* 30*th May,* 1845.

"Q. Are you of opinion that depths in rivers and their power of scouring are chiefly due to the volume of water brought down in freshes, or to the tidal waters?—*A. I should say to the tidal waters.*"—*D. Stevenson; Evidence before Tidal Harbours' Commission,* 4*th June,* 1845.

"In the lower portion of the navigation, *dependent on the tidal ebb and flow for its preservation,* it is manifest that accretion, to any considerable extent, must ultimately prove highly detrimental to the preservation of the navigable channel."—*Abernethy; Report on Ribble Navigation Bill,* 30*th April,* 1853.

"*I do consider it highly injurious to any river to shut out even* *one inch of the tidal water."—Bald; Evidence before Tidal Harbours' Commission, 30th April,* 1845.

"I think the volume of water entering any of our tidal harbours *should be most scrupulously maintained,* with a view of scouring the channel with as large a body of water as possible; and where channels are narrowed, it should be done also in conformity with this principle. *I think it quite possible to obtain a good deep rectangular channel for the progress of the tidal water-way, and at the same time to keep unimpaired the whole lateral area for the reception of the tidal water to produce the scour."—Scott Russell; Evidence before Tidal Harbours' Commission, 9th July,* 1845.

The concluding words of the last extract contain the germ of a system of river improvement, which will receive elucidation in a succeeding chapter; but confining present attention to the real meaning of the opinions above quoted, it will be seen, that as a whole, they are entirely concurrent: there is, indeed, scarcely a shade of difference between them; they are unanimous in declaring that *the entrances and lower reaches of tidal rivers are mainly dependent upon the amount of tidal water admitted,* and that any decrease in its quantity, by whatever means brought about, must, *as a consequence,* be followed *by the certain effects of* deposition, deterioration, and decay.

We shall now show how far these opinions are borne out by experience, by noticing the past and present state of several of our harbours; for in determining a broad principle such as that now under consideration, too much heed cannot be given to the language of facts.

"For several miles round the town of Rye, and immediately adjacent to the harbour, there are large tracts of marsh land, over the greater portion of which the sea was formerly accustomed to flow at every tide, and thus formed a considerable backwater, which operated as a scour to the harbour of Rye, and kept the channel open. The proprietors, however, uncontrolled by any guardian of the port, erected dams and sluices across the rivers a short distance above the town, and finally excluded the tidal waters.

"By these means the harbour, deprived of its backwaters, yielded to the mass of sand and shingle which rolled in with every wave, and which have now nearly obliterated the appearance of a channel.

"In March, 1812, a high tide blew up Scott's float sluice (one of the dams alluded to above); the sea flowed freely to Robertsbridge, 15 miles up the country; and the returning ebb, as it appears in evidence, so scoured the harbour, that vessels drawing 16 feet water could get up to the town."—*First Report of Tidal Harbours' Commission, 8th July,* 1845.

"The whole area formerly covered by the spring-tide waters of the Blyth (port of Southwold) was about 2000 acres, and that by means of the several embankments shown in the accompanying plan, that area has been reduced to 450 acres, or less than a quarter of the whole extent. * * * 4½ millions of tons of tidal water were thereby excluded on every common spring tide; and as three such tides occur at each new and full moon, or seventy-eight in a year, some notion may be formed of the enormous loss of scouring power sustained in consequence of these embankments.

"Southwold is entirely dependent upon tidal water for existence as a port."—*First Report of Tidal Harbours' Commission, 8th July,* 1845.

"The area of the estuary of the Dee was formerly about 12,000 acres, covered at every spring tide: of this space 8000 acres have been enclosed, and the tidal water excluded. The Act of Parliament that sanctioned this extensive encroachment required that a depth of 15 feet, at ordinary spring tides, should be maintained up to Chester; but the river was in so bad a state, in December, 1844, that a vessel drawing only 8½ feet water could not go up to Chester on a spring tide."

"At Parkgate, 12 miles below Chester, which formerly was one of the principal mail-packet stations between England and Ireland, a dry sand now extends almost across the estuary."—*Second Report of Tidal Harbours' Commission, 20th March,* 1846.

"Blakeney and Clay, on the north coast of Norfolk, have a common entrance from the sea: within the memory of some of the present pilots, 140 coasting vessels have taken refuge in this port during one tide; yet in the place where these vessels lay afloat at low water there is now only a depth of 4 or 5 feet, and the utility of the harbour has consequently been almost destroyed.

"It is stated that this evil has been caused by the enclosure, at different times, of more than 1200 acres of land, over which the tidal waters formerly flowed."—*Second Report of Tidal Harbours' Commission, 20th March,* 1846.

"The port of Wells lies a few miles to the west of Blakeney. The inhabitants struggled for nearly half a century to prevent the enclosure of the tidal lands by the adjoining proprietors, even at the expense of many suits at law; but all these efforts were frustrated, and 846 acres have been enclosed, to the great detriment of the harbour."—*Second Report of Tidal Harbours' Commission, 20th March,* 1846.

"Changes of this sort (shifting of entrance) are by no means uncommon: the harbours of Aberystwith, of Conway, of New Shoreham, and several others, are striking examples of this sort. When these rivers were in their original state, without embankments, the tide water flowed over a great extent of land in the interior of the country; and this water, assisted by the fresh water of these rivers, had sufficient power to scour out and preserve their entrances nearly in a straight direction; but as these spaces were diminished, either by the subsidation of alluvial matter or by embankments, the receptacles for the tide were diminished, and consequently sand-banks were lodged at their entrances."—*Rennie; Report on the Bar and Haven at Great Yarmouth, 29th May,* 1818.

"Rye Harbour has been ruined by embankments: it appears in evidence that formerly a 64-gun ship could use that harbour, which is now ruined."—*Rennie; Evidence before Rochester Bridge Committee,* 1820.

"There is little doubt that the harbour of Southwold has, at former periods, been of a much greater depth than it now is; * * * for many years past it has been getting gradually more shallow, owing to the embankment of the salt-marshes, over which the tide used to flow, and the stopping some of the creeks which communicated with the channel of the River Blyth. By these changes the influx of the tidal water has been diminished, and consequently the efflux, thereby diminishing the velocity of the current, so that the matter which formerly was not sufficiently heavy to resist its strength gradually became so; * * * the diminished force of the current will be nearly in the proportion of ten to four."—*Rennie; Report on Sole Harbour, 6th January,* 1820.

Even the Clyde, with all its manifest improvements, and they are neither few nor small, forms no exception to the rule.

This river, up to 1768, was in a state of nature for thirteen miles below Glasgow, and it appears from Dr. Cleland's Annals "that it was navigable only for craft of the smallest burthen, and the shores were so rugged and irregular that the tide spread over a great surface, forming pools and islands, which often caused the most skilful skipper to miss the channel." Since that period the improvement of the river, from Glasgow to its embouchure in the Firth of Clyde, *as to depth*, has been steadily carried out. Vessels of the largest class are now able to reach Glasgow quays: the dues, increased fifty-fold since 1770, are still increasing, and the whole has resulted in causing an immense addition to the trade, manufactures, population, and wealth of the city. This, however, is the bright side of the picture only, for in carrying out the alterations the original amount of tidal water, properly belonging to the river, has been materially reduced. Mr. Bald, the late resident Engineer, states, that quantities of sand and mud have been carried away from the upper down to the lower Clyde, and produced shoals and banks most injurious to the navigation, and which did not exist in 1768. That this is really the case, may be seen by turning to Golborne's Report of the 30th of November of that year, wherein the following expressions occur: "I find that the first obstruction to navigation is Dumbuck Ford;"—"The first and grand obstacle is Dumbuck Ford;"—"From Port Glasgow to the foot of Dumbuck Ford there are not less than 12 feet at low water;" whereas, on reference to Captain Robinson's 'Survey of the Clyde' in 1846, it will be observed, that the general depth in the same district is from 9 to 10 feet, *and in several places it is reduced to 6 feet, or half of the original quantity.*

Mr. Walker states in evidence before the Tidal Harbours' Commission, "The diminishing the reservoir for the tidal water in the Thames has had, in my opinion, the effect of increasing the shoals at its mouth;" and Mr. Abernethy, in his Report upon the Dee, the enormous abstractions from which river we have already noticed, remarks, "The lower part of the navigation is gradually filling up;" thus proving the correctness of Telford's prediction.

Were it not for overburdening the subject we could extend the reference to other striking instances of tidal reduction, and consequent decay; for the laws of nature being general and uniform, what is operative as a cause in one case is so in another; but the examples already adduced will be considered sufficient, as the facts concerning them are well known: the connection between the embanking and shallowing, the cause and the effect, cannot well be mistaken or questioned, and they are therefore so far eminently corroborative of the truth of the preceding opinions. It will only be necessary further to remark respecting this class of proofs of the soundness of the position assumed, that with such well-authenticated instances of harbour deterioration, it does appear extraordinary that any writer should be found declaring "they have not yet heard of any reasoning which explains in what manner the abstraction of the tidal space can or does produce the effects complained of." It might be supposed, that where the fact was so clear, the explanation of its cause would be equally apparent!

The following collateral facts have occurred in the writer's experience: though subordinate to those already described, they will not be considered superfluous if they assist in placing the doctrine under discussion beyond all question.

In 1838, Surveys were made of the entrances to the Tyne and the Wear, when a depth of 8 feet was found on the bar of the former river, and 3 feet on that of the latter; the low-water datum of both surveys being the same. Several years afterwards their outlets were re-examined, when it was found that the depth on Tyne bar had decreased 2 feet, while that on Wear bar had increased 1 foot. So singular and marked a difference in the case of two streams in such close proximity was not a little strange, as no natural cause could well be assigned for the change in the one case, without its being equally applicable to that of the other. A little inquiry, however, removed all uncertainty on the subject, for it was found to be the result of the difference of the systems pursued upon the two rivers. In the interval between the examinations the Tyne had been operated upon by most extensive works, the effect of which had been to exclude 34 millions cubic feet of tidal water from the river every common spring;* while, by

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* Full details of this loss form the subject of the third chapter.

the authorities of the Wear, the strictest conservation of this element had been persevered in, and its amount maintained or even increased. It is not here meant to be inferred that the differences above mentioned were the exact measure of the tidal loss and gain in either case, or that the bar is the best spot for applying the test; but it is submitted that they proved the *tendency* of the systems pursued, and the examples are so far valuable. This extreme jealousy in husbanding the meagre powers Nature had bestowed upon their river, was no new thing with the Commissioners of the Wear. Even as far back as 1756 they prevented an attempt to enclose the shore of the river, being convinced, it is said, "from their own experience, as well as by the advice of their Engineers, that embankments were prejudicial to navigation." They also defeated a renewal of the scheme in 1813, and continued to persevere in their measures of strict conservation and judicious improvement up to the time upon which we are remarking. The whole case is very instructive, and Sir John Rennie, in his place as President of the Institution of Civil Engineers, observed, "The entire system that had been followed was well worthy the attention of Engineers, as the port was a striking example of what might be effected by adopting correct general principles, and persevering in their execution."

Our attention has, up to this point, been confined to proving, that the entrances and lower portions of tidal rivers are dependent on tidal water, and that their outlets are to be improved or otherwise, according as the amount is preserved or wasted. We now take one step further, and show that a *bonâ-fide* fresh-water stream is powerless to maintain a sea outlet, and to keep down a bar. The example we select for illustration is that of the river Coquet.

This stream takes its rise among the Thirlmoor Hills in the western portion of Northumberland, and after a course of forty-four miles, or thereabouts, joins the sea, a short distance below the town of Warkworth. Being a mountain stream, it is subject to great variation in the amount of its discharge, and its fall being great, averaging 5 feet per mile for the latter part of its course, its tidal character is insignificant. The tidal influence only extends to 3¼ miles from the sea, and the total quantity of tidal water admitted at ordinary springs is limited to 32 millions cubic feet, being somewhat near the amount rejected out of the Tyne. The necessities of the district, however, requiring that some attempt should be made towards the improvement of the Coquet, works of an extensive character, and involving a large outlay, were entered upon, the effect of which, as described by their projectors, would be "to render the port equal to the Tyne and superior to the Wear, and to maintain at the entrance a depth of from 4 to 6 feet at low-water springs." The writer visited the harbour several years after the works had been carried out and their effect fully developed, when, instead of a free and unincumbered approach as was predicted, an all but dry bar, of a horse-shoe form, extended across the entrance from pier to pier!

Lastly, let it be remembered, that in the case of all the rivers referred to, the water-shed or area for drainage has remained untouched; the rain-fall has of course continued the same; the only difference is, that floods now pass off the ground more rapidly than they formerly did, and therefore, according to the well-known law of hydraulics, that "the force of water in deepening a channel is always proportional to the quantity acting in a given time," *their outlets, if due to the fresh-water stream, ought to have improved in proportion to the difference in the time of its delivery.* Such, however, has not been the case, and this fact, taken in connection with so many instances of decay, is not uninstructive upon the point we are considering; for it shows very clearly that dependence must be placed upon another power than that of the effluent water for the preservation of the embouchures of our rivers.

Having now, it is trusted, removed obscurity from what we cannot but term the *cardinal doctrine* of hydraulic engineering for tidal rivers, a groundwork is laid for a further profitable consideration of the subject. The examples described, though varying in character and importance, have a distinctness and significance belonging to them which add not a little to their value as elements for a general conclusion. The materials dealt with are simple: cause and effect are upon the surface and self-evident, and it is submitted that the whole substantiates to the letter the general correctness of the opinions quoted, viz., that *the navigable condition of the channels at the entrances and over the bars of tidal rivers, especially as to permanence and capacity, are entirely dependent on the influx and efflux of tidal water;* nay more, as decay surely follows loss, it is but fair to suppose that one is the exact measure of the other: the sectional size, in short, is reciprocally as the amount admitted, and any loss of the latter is immediately indicated by a decrease of the former. That such a connection should exist is quite in harmony with the laws of running water, and which will be fully explained hereafter; we only notice the fact at present.

The value we thus assign to tidal water as a fundamental principle is *universally applicable* whatever be the amount admitted. It is freely conceded that there is great difficulty in generalizing in river engineering, for circumstances vary greatly, and each harbour from its position and locality has peculiarities that require to be studied before works are adopted; but this restriction must be itself limited to matters of detail, for it does not affect the general principle. The supposed exceptions to its application are to be accounted for by applying it to an extent not warranted by the circumstances of the case, but in the cases themselves there is far more similarity than is generally admitted. No doubt rivers have what may be termed their constitution, and thus some depend more on the land waters than the tidal, as, for instance, the restricted Dee at Chester,—the Eye,—the Coquet,—the Esk at Whitby, and others; but the quantity admitted does not alter the case. Every portion of the tidal expanse, however small that expanse may be, has a value peculiar to itself, inasmuch as *it is continually operative:* every yard of it receives and returns a certain quantity of tidal water constantly, thus adding to the momentum of the stream, and consequently to its power for creating and maintaining an outlet. The only admissible view, therefore, seems to be, that any reduction of its quantity, directly or indirectly, insures an injury of a corresponding degree—*that such reduction is wholly against experience,* and must therefore be alike opposed to sound theory and successful practice.

CHAPTER II.

THEORIES.

AN EXAMINATION OF SEVERAL THEORIES WHICH, IN THEIR APPLICATION TO RIVER IMPROVEMENT, EITHER DECREASE THE QUANTITY OF TIDAL WATER OR DENY ITS USEFULNESS, VIZ.,

1. THE FLOOD STATE, THE GOVERNING STATE.
2. INDENTS DECREASE THE TIDAL VOLUME.
3. ENCLOSURE OF INDENTS ONLY FORESTALLS AN OPERATION OF NATURE.
4. DEPOSITION IN TIDAL RIVERS IS FROM SEA, AND NOT FROM LAND WATERS.

GENERAL INFERENCES.

HAVING laid down a basis of fact, from which we have deduced a fundamental doctrine, we proceed to discuss several prominent theories which may be considered as directly opposed to the position we have assumed.

1. *The flood state, the governing state.*

This theory, which declares that a fresh or flood is the governing power in both compartments of the river, tidal as well as fluvial, and that all improvement works should accordingly have reference principally to it, may be considered as having been partly refuted in the preceding chapter; for the examples there given of harbour decay resulting from tidal loss, the fresh water not having been diminished in quantity, are so many striking exceptions to the theory, and give to it an emphatic denial, so far as the lower portions of estuaries are concerned. If the theory had been restricted to the upper courses of rivers, it would have passed unchallenged; but as it has been extended over the whole stream without distinction, we must show its unsoundness in several particulars.

That the flood state is the governing state in the fresh-water river is evident, and needs no proof; for its dry gravel bed and abraded banks, while they point to the occasional presence of a powerful agent, mark at the same time its limit and its effect.

The various fluctuations of the effluent stream between its repose and feebleness at one time, and its turbulence and power at another, are all subjects of direct observation, about which there can be no mystery or mistake. Every feature which exists is at once referable to this, the sole agent, whose every action in each stage of its progress and variation of its volume may be made the subject of actual investigation, upon which may be reared a philosophic structure at once just and profound,—for it presents no feature which experiment cannot reach, or demonstration cannot fathom; but to constitute it the lawgiver in the tidal river, where its identity is lost and its effects cannot be distinguished, is, at the least, but a gratuitous assumption, and involves considerations entirely discordant with general observation.

To what, in the first place, is the tidal river owing?—for this naturally seems the first inquiry. There can be little doubt, on casting the eye over the broad landscape, that the action of water is everywhere apparent, and that many of the features we notice upon the earth's surface are due to it as a prime agent. The like operation is still active, but in a minor degree, as the changing causes are less numerous, and the work of ages has resulted in appearances of general permanence and stability. Hence we can readily perceive that at one period our estuaries, instead of being confined to their present narrow limits, occupied districts of considerable extent, the boundaries of which may even now be traced with great precision. The wide alluvial tracts upon the borders of the rivers upon the eastern coast,—particularly those of magnitude, such as the Thames, the Yare, those at the head of the Wash, the Humber, the Tay, and many others,—represent the difference between their ancient and modern sizes,—a fact which indeed is placed beyond question by the occasional exhumation of ancient barks in districts widely separated from the sea, thus showing very clearly that where the husbandman now bestows his labours, surges have rolled and keels have traversed. This esturial character of the primal sea-board afforded a degree of tranquillity favourable to rapid accretion, the materials for which would be plentifully supplied by the wastage of the more salient portions of the coast. We see exactly the same operation going on in our day in Lynn Wash, which divides the shores of Norfolk and Lincolnshire. The boundaries of this inlet have materially altered within the memory of man; they are still perceptibly changing, and it is proved from the researches of Professor Gordon, that the land near the Wash has accreted to the extent of 90 square miles since the time of the Romans. The material in this case has doubtless been brought by the waves from the crumbling coast of Holderness, which loses rather more than four million tons annually; and it is easy to foresee the time, when, by a continuation of the same process (even though it were unassisted by art), all the rivers now discharging themselves at the head of the gulf will occupy a common outlet where is now the deep sea,—when the waters of the Wash will be replaced by broad alluvial plains, similar to those already referred to. But setting speculation aside, the case affords sufficient fact to prevent our being left to conjecture, for we can readily understand by the example Nature is here working out, what has been her operation in days by-gone, and we are thus able to account for present appearances in a large class of our tidal rivers. In other cases we find them contained in valleys, which, instead of being due to the fluent waters, must have existed from the beginning, and nearly in the present form. Suffice it to say, that in the adjustment of the principal conditions of shape and size in our tidal rivers, the fresh-water stream has not been the architect.

Secondly. Can the principal features of the bed in the tidal compartment be referred to the land flood as a prime agent? We have already remarked that deeps, shallows, and dry banks, are common to both divisions of the river, fluvial as well as tidal. In the upper portion they are due of course to the action of the effluent stream either in one condition or another,—and the pools, and shallows, or falls, and counter-falls, we have assigned to a beautiful operation of Nature, whereby the accelerating force of a stream in descending a steep slope is made to produce an action destructive of its own power; but in the tidal compartment similar features proceed from a very different cause. Take up for instance a detailed plan of any tidal river, and notice carefully the deeper portions of its bed; they will invariably be found at the bends of its course, for the

Tidal
Rivers
[illegible]
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centrifugal force resulting from the sinuosity accelerates the stream, and an increased action and consequent deepening of the bed follows; but upon the stream resuming its straight course, its speed diminishes, and a corresponding shallowing takes place. This sketch of the cause of the profile of a tidal river is the rule to which there is no exception, so that, observing the course in any instance, the deep spots may be at once predicted. Here then (for a special reason exists for distinguishing between the two) we see that the alternate deepening and shallowing in a tidal river are *effects* resulting from the course marked out by a valley or an embankment *as the cause.* In short, features due to *slope* in the fresh-water river arise from *tortuosity of course* in the other.

Again.—The dry gravel banks in the fluvial river, representing the different conditions of bed required by the effluent stream in its feeble and flood states, have their counterpart in the flats, which, on the recession of the tide, are found occupying the indents of the tidal river; but in the latter case they arise simply from the deposition of the finer portions of the detritus, where, from the irregularities of its outline or its general course, the stream is least active; and we see that although similar features exist in the two cases, they are the effects of widely dissimilar causes. If therefore the tidal river, neither in its origin nor principal features, is due to the effluent stream, nor maintained by it, how can the flood state be justly styled the governing state?

Thirdly. It will be remarked that no discrimination whatever is attempted in the terms of the theory: they are absolute and comprehensive; and accordingly, whether the fluent be to the tidal river as a pigmy to a giant, the former is still to govern. We test this by some matter-of-fact data.

In the Thames at London, according to Mr. Walker, the tidal water in constant motion, passing and repassing, amounts to three million cubic feet per minute, while the usual land discharge in the same time is 150,000 cubic feet. Now, allowing this latter to be trebled during a flood, it then only amounts to one-sixth the usual average of the tidal water at London. If, however, we make the comparison at Gravesend, the disparity is enormously increased,—and if at the Nore, which agrees in position with the outlets of most rivers, then the land stream becomes too trifling to be an element of consideration.

In the Tay (still quoting from the same authority) the discharge, including that of the Earn, amounts during freshes to one million cubic feet per minute, or 240 millions during four hours. The tidal water passing Dundee in the same time is above 7000 millions (7,187,400,000) or thirty times that of the river water, and making the calculation at the bar, the tidal water is upwards of forty times that of the river water. It is well observed by Mr. Walker, that "it is only when the quantities are reduced to figures in this way that the vast disparity is seen;" and by Mr. Leslie, "I think that any effect from a fresh at the bar is a mere bagatelle compared with the scouring of the tidal water." If the same test be applied to the Humber, the Tees, and other of our tidal rivers of any size, a disparity greater or less will be found to exist in all of them; proving that in the great majority of cases the theory has absolutely no standing whatever. Measure also the sectional capacity of the bed at the upper and lower portions of the tidal river, and the latter will be found to exceed the former several hundred-fold in many cases. To what is this extra capacity at the outlet of the estuary owing? Surely not to the land waters, for, allowing that they receive no affluents in the interval, there is no natural reason why their conductor should be larger at one place than at the other.

No doubt in some rivers the flood on its occurrence is of greater comparative importance than in others, but, generally speaking, its abiding influence is confined to the head of the tidal river, where the oceanic flow being feeble, there is only one current of any strength, and that is downward. Take the Clyde for example, though many others might be instanced. The current of the tide flood through Glasgow Harbour is only half a mile per hour, while that of common freshes is 4 miles; and as the channel of any river is the balance of the disturbing powers, and is determined by their relative strength, it is clear, that the depth of Glasgow Harbour, in so far as it depends on current action, is due to the land waters, and not to the tidal current. At times also a flood may be sufficiently powerful to disturb the ordinary equilibrium of the whole tidal river, and a new channel for the time is formed for the altered circumstances of relative power. Thus we learn from Brand, the local historian, that a flood in the river Tyne in 1771 so destroyed the ordinary navigation "that the Newcastle Trinity Corporation ordered the pilots to make a survey of the new channel, in order to qualify themselves to lay the buoys in their proper places." This circumstance so far proves the disturbing power of an occasional fresh in the Tyne, but it proves nothing more; it does not touch the question of the maintenance of the sectional capacity of the whole belly of such a river.

To sum up the whole of the preceding argument as to this theory. Happily, as we have seen, the flood state is not the governing state in tidal rivers according to the true sense of the term; for where it has the preponderance, the fact cannot well be mistaken, since it implies (as in the Coquet for instance) an ordinary feeble stream, quite unequal to either the creation or the maintenance of an outlet fit for the purposes of commerce. We have shown, on the contrary, that in the case of the principal tidal rivers the proposition is wholly inapplicable, and that in the majority of the others there are certain circumstances as to capacity, which cannot be referred to the land waters as the cause. Were the theory to be limited to this, viz., that there is a condition in the tidal river as to depth of channel, which would not exist were it not for the effluent waters, it would be at once granted in a restricted sense; for in proportion to their extent, they add to the preponderance of the ebb over the flood, and thus supply a power to assist in the delivery of their own detritus into the sea; they aid in clearing a channel of a certain capacity, but which capacity is principally due to other powers than that of the flood. If, however, the theory embraces no more than this, *it practically amounts to nothing;* for it does not touch the question of the relative importance of the two powers for conserving the whole basin as a navigation and a receiver, *a point altogether vital in the proper consideration of the subject.* It is not sufficient to state, that in a limited sense the land flood is a governing power; it must also be proved a maintaining power in every stage of the tidal river,—for without this be the case, it does not possess sufficient importance to entitle it to a separate consideration, far less an exclusive one, in the projection of works for improvement.

2. *Indents decrease the tidal volume.*

This theory, though second in order, is first in importance, for it appears to be the fulcrum upon which much misconception as to river improvement rests, and is certainly the mainspring of a system of alteration which we cannot but deem destructive, and to furnish only examples of spoliation and decay. We purpose, therefore, bestowing a little time upon its investigation, desiring to present our objections in as simple a form and to be as brief as is consistent with the importance of the case.

First—The theory is this. It is assumed that as the descending stream diminishes in rate directly it meets with an expanse according to the known law, that "when the sections of a river vary, *the quantity of water remaining the same*, the mean velocities are inversely as the areas of the sections,"—the velocity of the upward current or stream of flood must also be diminished by such irregularities, and the total quantity of tidal water, which would otherwise have been admitted, is thereby materially reduced. The advocates of this theory have not paid due attention to an important condition of the law, viz., "the quantity remaining the same," for it is imperative that this be the case in both instances, or a comparison of effects is out of the question. To particularize,—whatever be the nature of the section through which the effluent water passes, let the current be accelerated or retarded thereby to any degree, it is clear that these variations in its velocity can have no effect whatever upon the *quantity* delivered, for that is fixed by the rain-fall, and independent of such causes; but with the upward stream the quantity is not fixed, inasmuch as the source of supply is inexhaustible. How widely dissimilar therefore are the two cases! it is apparent that there is no congruity between them on which to base a comparison. With one, it is rate with a fixed quantity—with the other, it is rate and an unlimited supply; in the downward current the velocities are reciprocally proportional to the amplitude of the sections, but this affords no clue whatever to what may be the case with the tidal flux.

In short, the advocates of the theory, we contest, before they can have the shadow of a standing in the way of argument, are forced to assume *as a fact* that which it is first of all their duty to prove *is* a fact.

Secondly. It is urged, that in the propagation of the tide wave up a river, it can receive no advenient aid from within—that all within is opposition, a portion of which is supplied by every indent, and that the stream ascends the river by its own inherent power, consisting of the external force or pressure of the undulation at the entrance to the river. Now if this be allowed to contain the whole case, and the theory be carried to the extent of its sanction, then the size of the receiver would form no portion whatever of the question, and whether the river be one like the Thames, or one like the Tweed, it would have no effect upon the quantity,—an assertion which renders an answer all but unnecessary. Size, however, is not so unimportant, and as in all tidal rivers lateral receptacles form a material portion of the whole tidal capacity, we proceed to consider what is their actual effect upon the upward stream.

We will suppose the tide wave to have arrived at the mouth of a river debouching at right angles to the line of coast. In this case it is apparent that no tidal water is due to the inlet as a matter of direction, for if the undulation continued to obey its forward impulse, it would pass the river altogether. Some power must therefore be applied to act upon the direction of the current, so as to attract it, as it were, out of its proper course. If a dead wall be placed across the entrance to such river, the tide wave would oscillate against it, but it could do no more; the elements for assisting in creating a momentum would truly be in the oscillation, but they would be latent only, and unproductive of inset or current action: Why? Simply, because the wall bars all *demand,* or, as we might put it, it prevents all *indraught,* for we have high authority for the use of the term.* Now let us remove the wall a few hundred yards within the outlet, and what do we see?—that the tide wave, which before was a mere oscillation, has now acquired an inward movement—not a rate of any consequence truly, but one

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* 'Indraught' occurs in Mr. Walker's Report on Yarmouth Haven, on 27th August, 1825.

proportioned to the space to be filled. To what, therefore, is the current owing? Not to the tide wave having undergone any change, for it would oscillate again were the wall replaced, but simply to the fact, that a space within the river has been provided for its reception, and a supply is accordingly given in proportion to the demand.

We will now place our barrier a quarter of a mile further up the stream, but in this last remove we include an extensive indent. We see that the current which before was sluggish, and "fed in," has now acquired, it may be, a double rate: why? Not that the source of supply has received new powers, but as there is a double demand, it is immediately followed by a corresponding rate, and as the indent contributes in this latter shift a portion of the space to be filled, it would need some ingenuity to prove that it does not, in proportion to its extent, supply also a part of the whole demand. So we might go on, shifting the wall and increasing the space, every portion of which would supply its quota to the general demand upon the outer reservoir, and the velocities in each stage being reciprocally as the demand, till we had reached the maximum capacity of the orifice at the entrance as a conductor to the rate of supply.

We must here guard against misconception. In using the term *indraught,* it is not meant that there is any such attractive influence in the river as the name would seem to imply, for gravity is the sole cause of motion from first to last, but the term conveys the idea better than any other, that the efficient cause of the current is within the river, and not without it,—it is truly the pressure of a certain head of water without, which assists in causing a current, *but it is the space within to be filled which allows a current to be generated.*

Allusion is sometimes made, in support of the theory we are combating, to a remark of Mr. Smeaton's, that "the tide is spent by many turns in a river and in filling the loops, and is thereby prevented from rising so high perpendicular as when the course is straight, and with a more regular contraction,—the tide passes by before the loops are filled." What, after all, does this really amount to? Mr. Smeaton's remark is confined to *height,* and not to *quantity.* He merely says, that by the rebounding of the stream from side to side, and the consequent increase of friction, the tide does not rise so high as it would do were the river made straight, *but he does not say that the same amount would be admitted in the altered receiver*. That illustrious Engineer was far too close an observer to deny the one, or to admit the other.

We see, therefore, how material a point the size of the receiver is in estimating the tidal quantity, and the causes by which it is influenced. What we have offered may at first sight be considered as overburdened illustration upon a subject which should be held as self-evident: that it is not so is proved by the theory itself, and the systems in harmony with it.

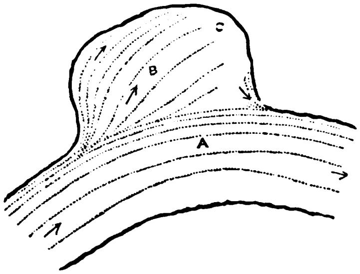
Again.—The direct effect of an indent is to increase the head of water, or difference of level between itself and the sea, and consequently to increase the velocity of the stream between the same points. We illustrate this by a familiar example.

The Falls of Niagara are supplied by the surplus waters of Lake Erie conveyed by the river Niagara, the whole length of which is about 16 miles. The river, on issuing from the lake, is rather contracted at the Black Rock, but it afterwards gradually widens, and dividing into two streams, sweeps round Grand Island. When reunited at a distance of 3 miles from the Falls, the river is considerably increased in rapidity: the acceleration continues to the Rapids, where the entire stream rushes over a rugged bed down a steep descent of 51 feet in half a mile, and then tumbles over the Fall. Here, of course, all resistance ceases, and the effect of it is to lower the level of the water at the Rapid, below what it would have been, had the river continued unbroken between the two lakes; and this lowering of the level at the Rapid increases the head of water, or the slope of the whole river Niagara, and its velocity to a like degree, and so renders it equal to the conveyance of the surplusage. Were a continuous river substituted for the Fall, the lengthened channel would increase the resistance, and the current would run slower till the rise of the level in lake Erie had generated an additional head, and hence an additional momentum to the stream, when it would again discharge the supply as before.

Apply this example to the case of an indent in a tidal river. The water runs into the indent precisely for the same reason that it rushes over the Rapids and down the Fall, viz., the action of gravity, inclining the particles to move on that side where there is a defect of pressure, and also from the pressure of the particles above them in the same direction; and, as in the case of the rapid the surface was lowered and the current above it quickened, so it is with the indent, for the cases only differ in degree. The common rate of rise in the rivers upon the eastern coast of England is about half an inch per minute, and hence the surface of the flowing stream abutting upon the indent will have a fall to a like extent: the surface will be lowered in proportion to the amount given off to fill the indent, and this again must add to the momentum of the stream, by increasing the difference of level between itself and the source of supply, for it is impossible to add to the head of water without at the same time supplying an accelerating force to the whole stream below that head. Therefore, as the quantity of tidal water thrown into a river mainly depends upon the size of the whole space to be filled, and as each indent adds to such space, it follows, from the properties of water, that every indent must contribute to the whole quantity a certain amount more than would be received if such indent did not exist.

Again.—Take a bird's-eye view of the movement of the flood stream while passing the dilatation, the low-water margin of which we will suppose to be well defined, as is generally the case,—we shall observe, that the same low-water boundary, or thereabouts, establishes an exact divisional line between the two streams; one of the river proper, representing an aggregation of the whole demand above,—the other, of the indent itself, determined by its superficial extent. On the river side of the line the rate is considerable, on the other side it is trifling in comparison; and it must be specially noticed, that the successive filaments of water due to the indent are not given off from the main stream in a direction at right angles to it, and so to retard it, but in gentle diverging lines, harmonizing with its general course. The following sketch will explain the movement; where the dotted lines at A represent the current of the river, and those at B the set into the indent;—C would be a position of rest.

Fig. 1.*



Again.—The effect of an indent upon the tidal flow has been likened to that of a bulb in a pipe, which has a retarding influence upon the passing water in the degree the diameter of the bulb bears to that of the pipe; but this has been stated as matter of opinion only, and no facts have been offered in its support. Now it is easy to conceive that the presence of excrescences in a pipe will cause confliction, and thus lessen the discharge; but its bearing upon the case before us is not very clear. It is evident that before any comparison can be made between the cases of the river and the pipe, they must be placed essentially upon a par. Suppose, for instance, that we have a 12-inch pipe with the water passing through it 12 inches in a second (although 30 inches would be nearer the usual rate),—then, to give a proportionate velocity to the stream in a river 500 feet broad, the current must run 300 miles per hour! and in one 1000 feet broad, 600 miles per hour!! Besides this extravagant disproportion between the usual rate of the flood tide in an estuary, and what it must needs attain to place it upon a par with the water in the pipe, a great difference also exists between the importance of the bulb to the pipe and that of the indent to the river. The bulb occupies the *whole round* of the pipe, and acts upon the whole stream passing through it, and the greater the rate the greater the resistance; whereas the indent is only a flat upon the side of the section, becoming operative on one side of, and in one condition of, the stream only. What comparison can be drawn between cases which have clearly nothing in common? It might

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* In all the diagrams the point of the arrow indicates the direction of the current.

as well be said, that if water met with no resistance from the bed in which it runs, if it had no adhesion to its sides and bottom, and if its fluidity were perfect, its gravity would accelerate its course continually, and therefore *it is* destructive, as that because an indent would be hurtful if the water ran at an inconceivable rate, therefore it can be of no advantage! *One sequence is surely as just as the other.*

Before we dismiss this section of our subject we must offer another example bearing upon the point, and it must be a familiar one. If we partly fill a vessel with water, and make a hole of a semicircular form through the side of it, reaching to a little below the level of the surface, the discharge from the orifice will cause the surface of the water in the vessel in the vicinity of the aperture to be sensibly depressed into a hole like the section of an inverted cone, and which effect is only gradually overcome as the water in the reservoir falls to the level of the bottom of the orifice. Now, if the motive power of the flowing water in this instance was pressure only, the surface within ought not to have been affected in the slightest degree, and the horizontal plane should have been preserved entire across the orifice *from lip to lip;* whereas the issuing stream evidently moves by its own gravity to the lower level, assisted, of course, by the pressure of the particles immediately following in the same direction. The example exactly applies to the subject before us, the sea taking the place of the vessel, and the river that of the orifice. The effect in the example is, of course, extravagant; but the *nature* of the effect is apparent, which is all that is here required.

Thirdly. Hitherto we have tested the theory by reasoning principally based upon the known properties of water; we now try it by a few practical examples which have a direct bearing upon it. If the theory be sound, the *first effect* of the enclosure of indents is to throw the tidal water, which would otherwise have entered them, into the up-going current, and thus to raise the level in the higher parts of the river by the amount thus added. It is clear also that the improved level, when once obtained, would not be afterwards lost, for allowing the new stratum of water to deepen the bed, yet the increase of volume would increase the momentum, and the energy of the deeper water would render the superior level permanent. Is this higher level from enclosures borne out by facts? Let us see.

Take the case of the Thames. This river has been most extensively embanked, as we all know, for no one can observe the broad alluvial plains below the solid slopes on either side without being fully aware of the fact. This restriction of the river by embankments dates from the earliest periods, history affording no trace of the time of their formation. Mr. Walker remarks upon them in terms singularly applicable to the point we are considering; he says, "As the banks are suited to the present level of the water, there are no grounds for supposing that the tides of the river now reach to a much higher level than when the embankments were formed; if they do, it must be caused by the tides at sea being higher than in ancient times, *for it would be unreasonable to suppose, that when the river extended to the foot of the rising ground of Kent and Essex, the tide would not attain a considerably higher level at and about London than it did at the estuary of the Medway, from the great width of the estuary at that time.*" In the present day the level of high-water spring tides at London is only 2 feet higher than that at Sheerness, 40 miles lower down, about the excess due to the form of the entrance of the river, and the direction of the tidal impulse, as we shall hereafter have occasion to show, under the head of 'Tidal Propagation,' Chapter IV. Where, then, is the tidal water which originally composed the ancient seas covering the Kent and Essex marshes? The only reply that can be given is, that as there is no demand for it, there is no supply.

Turn to the case of the estuary of the Dee at Chester. The identity of this broad inlet, as it anciently existed, is comparatively lost; for 8000 acres, or two-thirds of its whole extent, have been embanked, and the Dee, instead of flowing over a broad basin of great tidal capacity, is now confined to a narrow and artificial way through the new-made land. Where is the enormous quantity of tidal water which filled the ancient estuary? Surely not in the modern Dee, for the venerable city of Chester is not submerged.

The Clyde has been narrowed by improvement works to such an extent that it is necessary to restore to the river a part of the alienated alveus, to give a sufficient water-way for the increased traffic. Mr. Scott Russell mentions that the spring-tide high-water level at Glasgow rises 10¼ inches above that at Port Glasgow, an amount about due to the position of its entrance with respect to the tide wave intercepted in the Firth of Clyde. Mr. Bald says that "the high-water surface at Glasgow has not been influenced by the narrowing operations below the city." Where, then, is the tidal water which once filled the larger reservoir? Here the same answer necessarily follows—the supply only equals the demand.

One or two instances in addition will suffice. In the river Blyth in Suffolk, the whole area originally covered by the tide at high water was about 2000 acres, but this extensive space has been reduced by successive embankments to 450 acres, or less than a quarter-part of the ancient amount. Where, then, is the difference of contents? for the present stream only rises to a level line from the sea to Bulchamp Lock, the limit of the tidal flow.

In the Tyne (a river lately tested as to progress by the writer) nearly 100 acres have been cut off from the high-water space since the beginning of the present century, amounting to about one-sixteenth part of the former tidal superficies of the river between the sea and Newcastle bridge. Has the tidal water thus rejected been thrown into the up-going stream, so as to raise the level at Newcastle? A reply will be given in detail in the succeeding chapter, but here we may answer, No.

All the foregoing examples exhibit the theory practically carried out. If it be objected that the system is applicable to a certain degree, and no further, the examples given meet the statement at once; for though they embrace different stages of contraction, the result in one and all is the same, proving that the operations of Nature are entirely opposed to the theory.

Where, we may fairly ask, is the application of such a theory to cease? for if it be conducive to the conservation of force to cut off one indent, why not another? and as the whole of the *shelves* of the river form the bed of lateral receptacles, there are, according to the theory, cogent reasons for their enclosure also.

Allow them to be so enclosed, can there be any doubt (looking at the examples already quoted) as to what the result would be? Nothing less than the destruction of the tidal character of the river, and the conversion of the latter into a mere conductor for the land floods, which, after all, is the real effect of such a system, if carried forward to its ultimate issue.

In estimating the action of indents upon the tidal flow, *confusion has no doubt arisen from not making a distinction between the river as a* RECEIVER *and as a* CONDUCTOR. We illustrate our meaning by the Mersey as an example.

The narrow gorge opposite Liverpool is a connecting channel between two wider expanses; it is in fact the *conductor* of the tidal waters into the wide estuary above, or the *receiver*. Now we can readily imagine that the form of the sides of the conductor as to *continuity and parallelism* has a most important influence upon the whole amount of tidal water passed in a given time, viz., that of the duration of the tidal column. Any indent upon the side of such a channel must increase the friction, cause eddies and cross currents, and lessen the momentum of the passing stream, while supplying the demand above. An interesting hydraulic example in Comstock and Hoblyn's 'Manual of Natural Philosophy' has a bearing upon the case. "It is found that the velocity with which a vessel discharges its contents does not depend entirely on the pressure, but in part *on the kind of orifice* through which the liquid flows. It might be expected, for instance, that a tin vessel of a given capacity, with an orifice of, say an inch, in diameter through its side, would part with its contents sooner than another of the same capacity and orifice, whose side was an inch or two thick, since the friction through the tin might be considered much less than that presented by the other orifice. But it has been found by experiment that the vessel does not part with its contents so soon as another vessel of the same height and size of orifice, from which the water flowed through a short pipe; and on varying the length of these pipes, it is found that the most rapid discharge, other circumstances being equal, is through a pipe whose length is twice the diameter of its orifice. Such an aperture discharged 82 quarts in the same time that another vessel of tin, without the pipe, discharged 62 quarts. This surprising difference is accounted for by supposing that the cross currents, made by the rushing of the water from different directions towards the orifice, mutually interfere with each other, by which the whole is broken and thrown into confusion by the sharp edge of the tin, and hence the water issues in the form of spray, or of a screw, from such an orifice. A short pipe seems to correct this contention among opposing currents, and to smooth the passage of the whole, and hence we may observe, that from such a pipe the stream is round and well defined." In the conducting channel or the gorge opposite Liverpool, the tin is represented by the minimum section, the exterior side of the tin by the lateral expansion above it, and the short pipe by the amended channel. The enclosure of the indent upon the side of such a passage would of course involve a displacement of tidal water equal to its own capacity, but by the increased energy imparted to the stream by the straighter conducting side, the loss would probably be more than counterbalanced by the extra quantity thrown into the estuary above. We would here not be understood as *forcing a parallel* between the hydraulic example and the case we have connected it with, as it is evident they have little in common, but a slight similarity appears to exist, and hence we refer to it.

Lastly—To revert again to the theory. It must be clearly borne in mind that we have not had to consider whether, on account of the difference of friction, a reservoir with straight sides would not contain more tidal water at the instant of high water at sea, than a reservoir of the same capacity with indented sides; nor have we had to determine whether the tidal water which fills the indents at the sides would not be more useful in the centre. On the contrary, our attention, according to the terms of the theory, has been strictly confined to this,—is the amount rejected at the sides by the enclosure of indents restored in the centre? and both reason and experience, as we have shown, are against the supposition. But even allowing for example that the effect of lateral reduction is to raise the level in the higher parts of the river, then another inquiry immediately follows: *Is the increase there obtained equal, gallon for gallon, to the quantity rejected?* If not, it is fatal, as we have seen in the cases of decay mentioned in the first chapter, and as we shall have still further to show in the fifth.

To recapitulate. It has been explained, that as the idea of the ascending and descending streams being regulated by the same law is unsound, any theory based upon the supposition must be unsound likewise. Next, that the supply of tidal water from the sea is regulated by the whole demand of the river as a receiver, to which every indent or lateral receptacle adds its share; and that any theory advocating their enclosure with a view of increasing the tidal quantity is erroneous in principle, and quite opposed to the operations of Nature in their local modifications.

The connection of tidal propagation with river improvement works will be found near the end of Chapter IV.

3. *Enclosure of indents only forestalls an operation of Nature.*

This proposition, intended as a support to the preceding one, does not require much discussion for its refutation.

As far as we have gone, we have seen the primary value of tidal water, and the effect that each indent throughout the river margin has upon the total quantity admitted: if we can now prove in addition the comparative permanence of such indents, the folly of enclosing them follows as a matter of course. Here, again, we refer to a few practical examples as the best possible argument.

Jarrow Slake is a considerable inlet, embracing a space of upwards of 350 acres on the right bank of the river Tyne, about 3 miles above its entrance. It is abruptly recessed within the general margin on either side of it, and is therefore removed from the effect of any energetic current action. Mr. Rendel remarks in some late evidence connected with the river, "To show you how little deposit takes place where there is a moderate degree of exposure and stream of tide, I need only point out to you the present state of Jarrow Slake, as compared with its state in 1813 and 1837. I have brought with me a copy of soundings taken by Mr. Giles in 1813, retaken by him in 1837, and repeated on the same spot by Mr. Comrie in 1849." Mr. R. then proceeds to show that the result of each comparison was confirmatory of its unchanged condition. The writer can vouch for the substantial accuracy of this statement, for in the testing survey of the Tyne conducted by himself in 1849, Jarrow Slake was included, and the general depth over it had slightly increased rather than decreased since 1813.

Mr. Walker, in a letter to the Commissioners of Belfast Harbour, states, in reference to some slobs or flats at the head of the lough, that "the opinion is general, that the slob, particularly near the shore towards the upper or south end, is gradually silting up; and it is argued that the entire embanking now proposed is therefore of less importance. You pointed out to me on the ground a particular place, towards the upper end of the flat, which you said you remember to have been considerably deeper thirty years since than it now is, and that there the bottom, which is now mud, was then sand. I do not therefore doubt the fact of the above shallowing, and it is generally stated to have been in operation about forty years. Now, as this is about the time of the formation of Mr. Thomson's embankment, by which a considerable portion of the flat was enclosed, *and as the flat was in existence for probably many centuries before, the embanking and the shallowing appear like cause and effect;* and there is no doubt that any embanking of a portion of the slob has, by reducing the run of tide, and more particularly the scour or wash of the waves during winds, the effect of allowing a deposit to settle on the portion that remains unenclosed."

Professor Gordon, the Admiralty Inspector upon the Essex Embankment Scheme, says, with respect to the Blackwater, "The history of the estuary for the last century proves that if the mud-banks within increase at all, *they do so with extreme slowness;*" and further on, "We have here an estuary, *which, from time immemorial, has not changed in its high and low water features.*"

Other striking cases of permanency of level might easily be pointed out, as, for instance, the dry shelves of the Essex and Suffolk rivers, where they are very extensive; the mud-lands of the Thames; Breydon Lake, above Yarmouth; the Slakes of the Tees, and the Esks at Montrose, and many more of the same character; all proving that the rate of accretion is so slow that centuries appear to elapse without producing any marked difference in them. In fact, when the present deposits in many of the estuaries are considered, some of the flats, as they now appear, would seem to have required a long lapse of ages for their formation.

This feature, which may be termed a physical truth very generally admitted, is sufficiently remarkable in itself, especially in rivers where there is a plentiful material. The accommodation these shelves afford for detrital deposition (especially as there is little flowing or ebbing current over them) would long since have resulted in their obliteration, were not the equilibrium established by some power, effective in itself, and in frequent operation; which power, we have no hesitation in saying, is the lash of the wave, occurring during high winds in a river with any expanse. That this is really the case, any one may convince himself by watching the action of the surface waters upon a muddy flat in a windy day. The stroke of every lipper, small though it may be, has the effect each time of detaching and suspending a certain portion of the surface soil; and the same operation, constantly repeated through an hour or two of the latter part of a flood tide, is sufficient to convert what would otherwise be clear water into liquid mud. Let him revisit the spot on a calm day, and he will observe the water quitting the flat as uncharged with fluviatile matter as when it first covered it. A heavy fall of rain upon the flat has also a loosening effect, but in a minor degree.

It is unnecessary to add to the foregoing examples, for enough has been advanced to prove that the theory has no retrospective sanction, and that the practice of it forestalls an operation of Nature is by no means a necessary consequence; on the contrary, the conversion of flats or shelves into land is in reality an operation which Nature, in many cases, would not perform at all were she left to herself. While, therefore, every enclosure of the sort in a tidal river does a present injury by reducing the reservoir, it also (by lessening the expanse, and consequently the action of the surface wave) diminishes the means for preserving the portion of the tide basin contiguous to such enclosure, *and thus insures a future loss in addition.* Mr. Walker, in his remarks upon the Tay embankments, corroborates this view to the letter: he says, with reference to a proposed inroad upon the tidal receptacle, "The breadth, thus reduced by art, would be still further reduced by the natural formation of a foreshore in front of the dyke or bank, and this foreshore would gradually rise *above* the level of the reclaimed land within the bank. *Experience has proved this to be the progress in all similar cases.*"

Singular enough, cases are not uncommon where parties will allow the value of the tidal water in the shallow superficies, and yet, because they imagine they cannot retain it on account of the natural deposition, they at once reject it! This is a singular practice at the best, and the reasons for it are not very apparent.

We draw one important conclusion from the general fact we have been considering, viz., that if recessed flats appear to reach a culminating point, as it were, and are then all but permanent, *they would be fully so if they occupied an advanced instead of a retired position, and were thus subjected to current action, in addition to that of the wave-stroke.* The practical bearing of this remark we shall point out in a succeeding chapter.

4. *Deposition is from sea, and not from land waters.*

This is the last theory of importance requiring notice, and our remarks must be brief, as they have already in the preceding sections extended beyond the limits at first assigned to them.

This theory may be properly prefaced by a few condensed quotations from Sir Henry De la Beche's 'Geological Manual.' He remarks "that from the action of the atmosphere, the melting of snows, landslips, and the cutting power of rivers, considerable destruction of dry land is effected: local circumstances arrest a great portion of this detritus."—"The velocity of the stream regulates the power of transport: so that rivers, when short and rapid, may carry a large portion of their detritus forward; while, when long, they leave a considerable portion of it in their courses."—"The power of a river to transport detritus will be observed to be greater or less in proportion to the volume of water, the inclination of the bed, and the resisting power of the bottom and sides: the finer particles being more easy of transport, there are few rivers which during freshes do not carry a great quantity of such detritus into the sea. If the mouths of the rivers be tidal, the river detritus is committed to the charge of the estuary tides, and is dealt with *according to the laws by which they are governed.*"

The river is, in short, the conduit for an enormous quantity of fresh material from the interior of the country, constantly being transported and discharged into its storehouse, the sea; and such matter ultimately appears as the alveus or general bed of the German Ocean, which is in this way receiving constant additions from the circumjacent rivers. The effect of rivers being thus made the channel of transport to matter heavier than the water itself, and requiring a mechanical energy in the water to keep it suspended, is shown by their gradual reduction in size. The operation of deposition thus constantly going on, is in itself very simple. The matter with which the water is charged in a greater or less degree subsides, and fixes itself whenever it meets with a place of rest, the principle by which it is suspended being, as above remarked, the movement and agitation of the water; and whenever this ceases, deposition immediately follows. Each stage of accretion decreases the general motion, and a more rapid change in size ensues towards the completion of the operation. Those parts of the channel most distant from the sea first lose their depth, in consequence of the state of rest caused by the confliction of the land water and the flood tide in that part of the river. Generally speaking, all estuaries have a tendency to be filled up by constantly augmenting deposits from this cause, by which their beds are imperceptibly raised above their ancient level. This natural process is subtle, but no less certain.

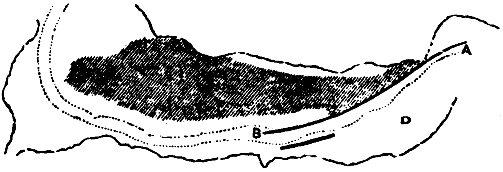
One or two facts may be given, to show the highly charged state of the flood waters. The Humber is a remarkable instance of the sort. That the estuary of this river once occupied a more extensive district than at present is apparent from the vast tracts of marsh land by which it is bounded; in many cases these alluvial plains are below the high-water level of the Humber, and in the majority of instances are raised but little above it. The cause which has produced these extensive changes consists in the highly charged state of the waters of the river, to an extent almost peculiar to itself, arising partly from the wastage of the Holderness coast, but more especially from enormous quantities of fresh material being constantly poured into it by its affluents. The quantity of deposition resulting from it is immense: for instance, nearly 100,000 tons of silt are on an average annually removed by dredging out of Hull Docks, and were this cleansing process not constantly repeated, they would wholly warp up. The large district of Sunk Island has sprung into existence in comparatively recent times from the same cause. In Leland's 'Itinerary' is a letter from the Rev. Francis Brokesley, dated 1711, giving an interesting account of this new territory; he says, "When I first went into Yorkshire, 44 years ago (1667), Sunk Island was spoken of as a novelty: it is now 7 miles about, and in forty or fifty years the channel, 2 miles broad, now separating it from the main, is expected to be wholly filled up;" a prediction which received its entire fulfilment in 1799. The quantity embanked in 1764, which amounted to 1500 acres, had been increased up to 1833 to rather more than 5929 acres. Since the Admiralty Survey of 1823, made by the late Captain Hewett, two enclosures—one of 1080 acres and the other of 700 acres—have been added to the extent of the island. The last embankment was completed in 1850, and new growths are already rapidly forming beyond it.

It is observed in the Tyne and Wear, and no doubt the circumstance is common to other rivers, that after floods the recesses at the sides, formed by piers, landing-places, and slipways, are all covered by a deposit of the finer particles of the alluvion to a depth of several inches, an effect which the highly coloured state of the descending stream would have led one to infer. This fact, recently noticed by the writer, inclines him to the belief, that if it were possible to test the point by actual measurement, the capacity of the whole tidal basin of the river would be found to be less after a flood than before it. Mr. Leslie, on the subject of river depositions, remarks, "Generally, in my opinion, there is more deposit in river harbours from the river than from the sea;" and Mr. David Stevenson, in reply to the question, "What is most to be feared, detritus brought down by the stream, or carried in by the sea?" answers, "In general, I should say, that the detritus brought down by the fresh water is more to be feared."

Silt
whence
from

Visit, also, any of the minor tributaries of a river after a fresh, and the banks on either side above the general level will be found covered by the finer particles of the detrital matter—the deposition left by the swollen rivulet. If the feeders are thus charged, there can be little doubt as to the condition of the aggregate stream.

Fig. 2.



We offer only one more example, and that is an interesting one, supplied by the Lune. Fig. 2 contains a portion of the river from Oxcliff to Glasson, in which A B represents a low training wall, placed by the Messrs. Stevenson in 1847 for the improvement of the navigation. In 1851, when the river was re-examined, it was found that the whole of the lined-in space C, *below the wall*, had risen or silted up, either from the altered disposition of existing materials or from fresh matter, while the bed at D, on the contrary, had scoured to a lower level. Had the supply of material in this instance been from the sea, the particular action of the wall upon the passing current would have caused the deposit to be at D and not at C.

It may be stated as a necessary appendage to the facts already adduced, that the principal sands on the sides of any river will be found below projecting points, stretching as a long pendant *below the point, and not above it.* The main channels follow the same rule by conforming to the direction of the ebbing water, proving very distinctly the decided preponderance of the power of the ebb over that of the flood.

We have now shown that the supply of matter is from the interior, and that the strength of the ebb to discharge it is greater than that of the flood to return it; and the theory cannot be correct which assumes that the deposit is from sea, and not from land water, *without Nature reverses her law of relative power,* and makes the weaker agent in effect the stronger.

It has been urged "that if the ebbing waters have an excess of power over those which flow, a greater quantity of sand would be carried out than is brought in, and the depth would consequently increase;" but it may be said, on the other hand, and with equal justice, that if the deposition is from the sea water, and every tide brings in its quota, how is it that we have any estuaries at all, seeing the enormous interval of time which geologists say has elapsed since the present state of things began? If, indeed, the material to be removed was confined to the bed of the river itself, *as the only source of supply*, with the movement of the soil dependent on the comparative transporting strength of the ebb and the flood, the objection would be valid, but inasmuch as the soil removed by the superior power of the ebb is soon replaced by a fresh supply from the interior, a certain balance as to quantity is constantly preserved.

Misapprehension on this point has no doubt arisen from observing that the deeper channel or gutter caused by the passage of a fresh is lost immediately the river returns to its usual volume, and this fact has been confounded with a general silting up, and accepted as an index of what would be the case were there no floods. It is not unfair perhaps to hazard an opinion, that an undue prominence given to this point lies at the root of at least one of the theories we have been considering. A little more reflection, however, would show that the apparent silting up was simply a return to the state of equilibrium disturbed by the fresh. "Every kind of soil has a certain velocity consistent with the stability of the channel; a greater velocity enables the waters to tear it up, and a smaller velocity permits the deposition of more materials from above." A fresh, then, by destroying the ordinary balance, results in a deepening and derangement of the bed, but the latter returns to its *mean state* again on the subsidence of the flood; the effect, in short, ceasing with the cause.

The idea of sea deposition may also partly have arisen from observing the effect produced upon the dry sand by the flowing water. How common is the remark, "The sand is all alive during the flood, but fixed during the ebb." The feature which has been misinterpreted is a very marked one. If, for instance, we walk by the sea-shore during the flowing tide, though the level of the water may be several feet below, yet the sand will be found in a semifluid state, and each foot-print in a short time forms a small pool of water, whereas, with the falling water, the sand is firm, and increasingly so as the tide falls and filters from it. This phenomenon results from capillary attraction, whereby, in porous substances, water is enabled to rise above its own level; but after the sand is once covered, the attraction necessarily ceases, and the sand is acted upon by the forces imparted to the water, *entirely irrespective of its belonging to the flood or the ebb.*

There are several other theories of river treatment of a minor order which cannot be noticed in a brief work like the present. The errors characterizing those we have discussed arise chiefly from extending the laws of running water over the tidal stream without sufficient warrant; then to a neglect of physical truths, about which there can be no doubt, and which are therefore the best exponents of laws yet to be discovered, but which, from their nature, are independent of the common operations of the experimentalist. Professor Robison very justly remarks, that "when we turn our attention to material objects, and without knowing either the size or the shape of the elementary particles, or the laws which Nature has prescribed for their action, presume to see their effects, calculate their exertions, and direct their actions, what must be the consequence? Nature shows her independence with respect to our notions, and always faithful to the laws which are enjoined, and of which we are ignorant, she never fails to thwart our views, to disconcert our projects, and to render useless all our efforts." Again, "To suppose what we do not know, and to fancy shapes and sizes at will, this is to raise phantoms, and will produce a system, but will not prove a foundation for any science."

It must be admitted by the candid inquirer that there are complex circumstances in a tidal river which constitute it a case by itself, and that it possesses compound elements and unknown quantities which experiment has neither detected nor determined. What example can possibly embrace all the conditions? What is to represent, *as an exact measure,* the effect of irregularities in its slope, its bed, and its sides—the confliction of currents and eddies—the compound action of its tidal and effluent waters—their alternating preponderance, and their comparative effects in different parts of the estuary? Without undervaluing experiment in its proper place, it is clear it cannot be applied in a case like this, and that it is very possible to watch the placid movement of water through troughs, or the sportings of a mill-race, and yet fail to detect one of the laws which obtain in the tidal river, either in its nature or in the extent of its application.

On the contrary, "To interrogate Nature herself, study the laws which she so faithfully observes,—*catch her* (*as we say*) *in the fact*, and thus wrest from her the secret; this is the only way to become her master, and it is the only procedure consistent with good sense." We shall not add to these sentiments of the learned Professor, but proceed to describe a few special examples which Nature has, as it were, worked out for our guidance; examples which, besides confirming many of the views contained in this chapter, will show, among other things, how impossible it is to force upon Nature a principle with which she is in direct hostility.

CHAPTER III.

REMEDIAL MEASURES—LATERAL REDUCTION—ITS NATURE AND ITS EFFECTS SHOWN BY THE CASE OF THE TYNE—PHYSICAL DESCRIPTION OF THE RIVER—RENNIE'S SURVEY AND REPORT—THE RIVER WORKS—BILL FOR A CHANGE OF CONSERVANCY—ADMIRALTY SURVEY AND ITS OBJECT—COMPARISONS AS A TEST OF PRINCIPLE—GENERAL BALANCE OF LOSS AND GAIN FOR THE WHOLE RIVER—INFERENCES AND CONCLUDING REMARKS.

A FEW WORDS UPON THE USE OF TRANSVERSE GROYNES AS A MEANS OF RIVER IMPROVEMENT.

DIFFERENT estimates of the powers of a tidal river necessarily entail diversity in the mode of treatment; but, omitting minor differences, river operators may be divided into two classes or schools, and called *lateral reducers* and *longitudinal trainers;* these terms embracing the peculiarities of the respective systems. The first-named will claim our present attention.

Lateral reduction is that which the term implies—a cutting off of those loops and embayed portions in the margin of the stream, which we have said are common features in most tidal rivers. The course is thereby restricted within certain limits, and reduced to uniformity; an uniformity, be it remembered, entirely irrespective of the general form in which the river has been received from the hands of Nature, and which may not improperly be termed the balance of necessity in each case, or *the way in which she has answered all demands.* Without entering here into a detail of the various causes to which sinuosities of course, and obstructions in the bed of a river, are owing, as it will follow in order, it is sufficient to remark that the end proposed by the advocates of lateral reduction is excellent. They urge, and very properly so, that the effect of irregularity in the course of a river is partly to destroy its action by causing lateral shelves and central shoals, whereby the channel is disjointed and rendered irregular in breadth and depth. Under such circumstances, and with a bed of shifting materials, the stream is easily turned aside by the slightest nucleus or obstruction, and there is no security for the channel being maintained in the same track for two following tides. Accordingly, as an excess of breadth would seem to be at the root of the evil, a decrease of it would also appear to be the most natural remedy. If, with the conversion of these superfluous spaces into land, the channels contiguous were improved, the same quantity of tidal water maintained, and the lower portion and the entrance of the river not affected injuriously, then the advantages of the plan are obvious; for the valuable frontage thus acquired would afford increased facilities for commercial purposes. There is, in truth, much in the system to recommend it at first sight, but its soundness can only be determined in the case of a river thus treated, and where it is possible to refer the altered bed to an original standard, whereby the exact loss and gain may become immediately apparent. Such an instance presents itself in that now about to be described, the writer only premising, that in detailing the facts, he answers at the same time for their entire accuracy.

The river Tyne, having at its outlet the principal port in the north of England, is formed by the confluence of the North and South Tyne near the town of Hexham, from whence it flows in an easterly course to Ryton, 18 miles from the sea, where the influence of the tide is first felt. After several remarkable loops like those of the Thames, the river passes Newcastle a stream averaging 500 feet in width. At Bill Point, 3 miles lower down, and where may be termed the head of the estuary, the river rapidly increases in breadth, and its bed is partly occupied by extensive shoals which dry at low water. After passing the deep indent Jarrow Slake upon the right bank, the Tyne contracts considerably, and forms for the last 2 miles of its course the noble harbour of Shields, at the lower portion of which the river joins the sea under the shelter of the promontory of Tynemouth, 10 miles below Newcastle, and 80 miles from its most distant source. The whole basin drained by the river has been estimated at 1100 square miles.

From the earliest periods the charge of the Tyne had been committed to the Corporation of Newcastle, who, in their character of conservators, levied certain dues for its improvement, but the river remained in a state of nature till 1813; many documents, more or less perfect, showing its condition up to that time. Rennie was then called upon to report upon the river, and under his direction an elaborate survey was made by the late Francis Giles; a work, which for scale, detail, and general completeness, will compare with the best of the present day. Rennie submitted his Report in 1816, containing a general description of the defects of the river, with several recommendations for its improvement, of which the following is a digest. The river was to be contracted in its wide places, and enlarged where too narrow, so as to give a general uniformity of width throughout; and, for this purpose, any projecting points obstructing the current were to be cut off, while the contractions were to be made by jetties from each shore reaching to *half-tide height; that the sand and gravel should be dredged out of the intended channel,* and deposited in the space between the jetties, and when the channel was brought by these *dredging operations* to the depth it was expected would be maintained, then the ends of the jetties were to be connected by longitudinal walls of rubble stone. So far as to the general scheme, the effect of which Mr. Rennie expected would be, to deepen the contracted portion, and by depressing the low-water surface to a corresponding degree, assist the propagation of the flood, and allow of its flowing to a greater height and distance in the higher parts of the river. Mr. Rennie, in his Report, strenuously insisted upon the value of the tidal element, *and the whole drift of his aim respecting it seemed to be, that while he improved its efficiency, he strictly maintained its quantity.*

These documents reposed in the archives of the Corporation, and were not acted upon, the river remaining in the same state until 1836, when a change in the constitution of that body occurring, measures for the improvement of the Tyne were determined upon, and the works were carried out with more or less steadiness up to 1849; but the system of alteration adopted differed essentially from that recommended by Rennie, or rather, *it had nothing in common with it.* The breadth of the river was reduced to a greater extent than he proposed; jetties reaching above high-water springs instead of half-tide groynes were adopted; the longitudinal walls for connecting their ends were all but omitted; instead of removing obstructions from the channel by dredging, as practised upon the Clyde, and recommended by Rennie, dredging, as a means of improvement, was entirely neglected, while the spaces between the jetties were filled in by imported and other foreign matter, such as ships' ballast, cinders, and general refuse. In short, the system pursued, instead of being that submitted by Rennie, was rather its converse.

Many complaints arising about the navigable condition of the river, and the two towns of Shields feeling their growing importance, and that the time had arrived for their having a voice in the management of that on which their prosperity so much depended, a Bill was introduced into Parliament in the spring of 1849, with the object of transferring the conservancy of the Tyne, and the dues properly belonging to it, into the hands of a body of Commissioners selected by the Admiralty and the various towns on the banks of the river. Much valuable evidence as to the past and present state of the port was given on the preliminary inquiry before Captain Washington, R. N., the Admiralty Inspector: the Bill passed the Commons, and was in the Lords, but was eventually withdrawn, the session ending abruptly. As statements respecting the state of the river of a more than usually conflicting character had been made before the Inspector, from among which it was next to impossible to arrive at the whole truth, and the advocates for the enfranchisement of the Tyne feeling that something of a more definite character in the way of evidence would be required by the Legislature to satisfy them of the justice of their case, application was made to the Admiralty for one of their Surveying Officers to undertake the examination of the existing state of the Tyne. The permission was at once granted, the writer being the party appointed for the purpose.

A complete survey of the tidal Tyne below Newcastle Bridge was accordingly entered upon, and completed during the summer of 1849; and the comparative state of the river was tested with the greatest carefulness, the basis of the comparison being Rennie's Survey of 1813. Evidence embodying the result was given by the writer before the Admiralty Inspectors and the Parliamentary Committees in the spring of 1850. In due time the Tyne Conservancy Bill passed into law, and the management of the river was committed to Commissioners, representing to a certain extent the interests of all the communities on its banks, and in whose hands it still remains.

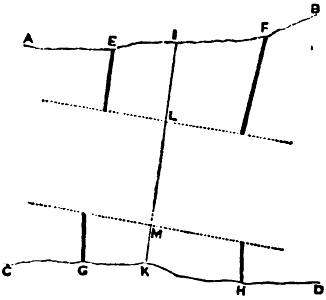
Though the material facts resulting from the comparison are to be found in the parliamentary records of the period, they are principally confined to a simple balance of loss and gain, and do not include those points of detail elucidating the principle of treatment, and the laws by which Nature appears to be governed in such a case, and which are so valuable to the student. While here supplying the deficiency, we shall endeavour to render the explanation so simple, that it may be readily understood by the unprofessional reader. The loss and gain for the entire river within the limits of the survey will be given before concluding the chapter.

The case afforded singular facilities for instituting an exact test of progress, for the whole bed of the river had been referred in Rennie's Survey to the high-water mark of May 31st, 1813, which was found to be an exact level, and was accordingly indicated by a legible notch in the south-west corner of the Low Light-house at Shields: 286 transverse sections, showing the depth of the bed of the river below this datum, had been taken between Shields and Newcastle Bridge: it was only necessary therefore to identify the position of each section, and to re-sound it, when differences of capacity would be immediately apparent. In this way, the high-water and the low-water areas, with the 3, 6, 9, and 12 feet low-water channels, and the tidal contents at the two periods, were tested. In short, each of the 286 sections became a point for a distinct and rigid comparison, the truth of which could neither be controverted nor doubted.

The principal artificial works are situated on both sides of the Tyne between Jarrow and Hebburn, at the broadest part of the estuary, and nearly in a central position between Shields and Newcastle. It has already been observed, that the works consist of transverse wooden groynes reaching in height above high-water springs; their length (regulated by the required contraction) extending in several instances to upwards of 700 feet, or nearly half the breadth of the river; and some of the spaces between them being filled up by ballast and other matter, and formed into land. The portion of the river between

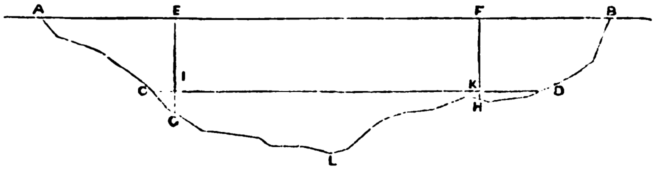
Jarrow and Hebburn included 76 of Rennie's sections,—and its state before the works were commenced, and after they were projected, is shown upon Plates A and B, at the end of the Treatise; the former being an exact reduction from Rennie's Survey of 1813, and the latter a similar reduction from the Admiralty Survey of 1849. The altered circumstances of this important portion of the tidal river are therefore readily seen by a comparison between the two.

Fig. 3.



The following Table contains the details of the exact loss and gain in the 76 sections, that is, the amount each section has been reduced at the sides by artificial works, contrasted with the additional depth gained in the centre by the consequent increase of scourage. The nature of the quantities contained in the Table will be better understood by referring to figure 3, in which A B and C D represent the original high-water boundaries; E, F, G, and H, transverse groynes, and the line I K one of Rennie's sections. In this case, instead of the current ranging as formerly between A B and C D, it will be bounded by lines joining the points of the groynes on either side. Hence, in the section I K, the current will pass between L M, while the extremes L I and M K will be in still water. One of the objects of the Table therefore is to show what effect this restriction at the sides has had in depressing the bed, expressed by L M.

Fig. 4.



Or, again,—Figure 4 is a projection of one of Rennie's sections, in which A L B represents the bed of the river, A B and C D the high and low water lines, and A E and B F, transverse groynes from either shore, confining the current to the space E F. In the sides of the section thus cut off by the groynes A E, I C, and B F, K D are tidal spaces, and C I G and D K H are spaces below low water. The object of the quantities in the Table is to show what proportion the depression of the bed between G and H bears to the whole lateral reduction A E G and B F H. In this branch of our subject it does not matter what may be in the lateral spaces, land or water, as that will receive a separate consideration.

The numbers of the sections correspond with those upon the lithographed reduction of the Admiralty Survey attached to the Minutes of Evidence.

The quantities in the Table are square feet.

No. of Section.	H. W. Sectional Area of Bed from Rennie's Survey.	Contraction of Section by Artificial Works.			H. W. Sectional Area between points of Contraction.		Effect of Increased Scourage between points of Contraction.	
		Tidal Space.	Below L. W.	Total Contraction.	From Rennie's Survey.	In 1849.	Increase.	Decrease.
72	23,556	1,300	..	1,300	22,256	22,950	694	..
73	23,940	907	..	907	23,033	22,990	..	43
74	23,530	1,088	..	1,088	22,442	22,245	..	197
75	24,544	1,220	..	1,220	23,324	22,597	..	727
76	23,887	1,385	..	1,385	22,502	22,208	..	294
77	24,176	1,284	..	1,284	22,892	23,143	251	..
78	24,510	1,572	150	1,722	22,788	23,341	553	..
79	24,621	2,240	150	2,390	22,231	22,950	719	..
80	24,475	1,625	..	1,625	22,850	22,034	..	816
81	23,140	1,677	..	1,677	21,463	21,131	..	332
82	23,237	2,380	..	2,380	20,857	20,257	..	600
83	21,340	1,440	..	1,440	19,900	20,450	550	..
84	20,364	1,170	..	1,170	19,194	19,600	406	..
85	19,885	1,400	..	1,400	18,485	19,980	1,495	..
86	19,238	1,680	..	1,680	17,558	18,840	1,282	..
87	19,680	2,200	..	2,200	17,480	18,760	1,280	..
88	20,910	4,030	25	4,055	16,855	17,460	605	..
89	21,320	5,325	80	5,405	15,915	16,440	525	..
90	21,970	6,656	150	6,806	15,164	15,782	618	..
91	22,068	7,128	270	7,398	14,670	15,408	738	..
92	21,800	7,000	450	7,450	14,350	16,850	2,500	..
93	21,456	7,155	300	7,455	14,001	15,930	1,929	..
94	22,684	6,905	290	7,195	15,489	16,320	831	..
95	23,363	6,482	201	6,683	16,680	16,969	289	..
96	22,410	6,770	160	6,930	15,480	16,910	1,430	..

No. of Section.	H. W. Sectional Area of Bed from Rennie's Survey.	Contraction of Section by Artificial Works.			H. W. Sectional Area between points of Contraction.		Effect of Increased Scourage between points of Contraction.	
		Tidal Space.	Below L. W.	Total Contraction.	From Rennie's Survey.	In 1849.	Increase.	Decrease.
97	22,607	6,950	..	6,950	15,657	16,400	743	..
98	22,575	5,918	37	5,955	16,620	16,060	..	560
99	21,363	5,840	..	5,840	15,523	16,440	917	..
100	21,418	4,999	50	5,049	16,369	15,714	..	655
101	19,910	4,470	217	4,687	15,223	15,980	757	..
102	20,931	4,595	298	4,893	16,038	15,158	..	880
103	21,535	5,572	133	5,705	15,830	15,120	..	710
104	22,200	8,040	300	8,340	13,860	15,090	1,230	..
105	22,947	9,000	170	9,170	13,777	14,760	983	..
106	22,620	8,990	180	9,170	13,450	15,180	1,730	..
107	21,866	9,200	350	9,550	12,316	14,540	2,224	..
108	22,440	9,970	550	10,520	11,920	13,850	1,930	..
109	22,490	9,310	830	10,140	12,350	13,850	1,500	..
110	22,133	8,850	855	9,705	12,428	13,640	1,212	..
111	21,635	8,450	740	9,190	12,445	12,960	515	..
112	20,956	8,060	680	8,740	12,216	13,140	924	..
113	20,605	6,930	560	7,490	13,115	13,670	555	..
114	20,640	5,873	430	6,303	14,337	13,365	..	972
115	19,933	5,740	600	6,340	13,593	14,110	517	..
116	19,856	5,592	850	6,442	13,414	13,883	469	..
117	20,021	5,650	1,260	6,910	13,111	14,200	1,089	..
118	20,520	6,350	2,005	8,355	12,165	14,580	2,415	..
119	22,230	5,640	2,250	7,890	14,340	14,900	560	..
120	21,687	6,330	2,320	8,650	13,037	16,150	3,113	..
121	21,312	6,650	2,625	9,275	12,037	15,680	3,643	..
122	21,817	7,670	2,400	10,070	11,747	15,600	3,853	..
123	21,760	8,350	1,980	10,330	11,430	15,400	3,970	..
124	22,957	8,400	1,890	10,290	12,667	15,150	2,483	..
125	23,846	8,450	2,000	10,450	13,396	15,000	1,604	..
126	24,213	9,400	2,170	11,570	12,643	14,180	1,537	..
127	24,665	9,684	2,270	11,954	12,711	14,520	1,809	..
128	24,255	9,634	2,165	11,799	12,456	14,600	2,144	..
129	23,623	8,700	2,020	10,720	12,903	15,000	2,097	..
130	23,343	7,860	1,500	9,360	13,983	15,150	1,167	..
131	23,274	6,700	1,615	8,315	14,959	16,270	1,311	..
132	22,200	5,859	1,050	6,909	15,291	16,106	815	..
133	21,315	4,980	1,100	6,080	15,235	16,230	995	..
134	20,535	3,539	460	3,999	16,536	15,849	..	687
135	18,430	2,965	200	3,165	15,265	16,420	1,155	..
136	17,357	2,427	150	2,577	14,780	15,850	1,070	..
137	17,173	2,225	..	2,225	14,948	15,015	67	..
138	16,803	3,145	..	3,145	13,658	14,400	742	..
139	16,827	3,150	..	3,150	13,677	14,335	658	..
140	16,636	3,300	..	3,300	13,336	14,726	1,390	..
141	16,291	2,530	..	2,530	13,761	14,408	647	..
142	16,004	2,295	..	2,295	13,709	14,329	620	..
143	15,700	2,080	..	2,080	13,620	13,640	20	..
144	14,900	1,559	..	1,559	13,341	13,187	..	154
145	14,945	1,610	108	1,718	13,227	13,510	283	..
146	15,238	1,950	240	2,190	13,048	12,505	..	543
147	14,248	1,810	390	2,200	12,048	12,113	65	..
Total	1,606,889	385,260	44,224	429,484	1,177,405	1,243,458	74,223 8,170 66,053	8,170

Sectional loss by Contraction, 429,484; Sectional gain by Increased Scourage, 66,053.

The comparison shows *that the gain in the centre from increased scourage amounts to less than one-sixth of the loss at the sides:* the former, in fact, is but little more than equal to the space below low-water mark cut off by the works, *and there is accordingly no equivalent for the sectional loss in the tidal space.*

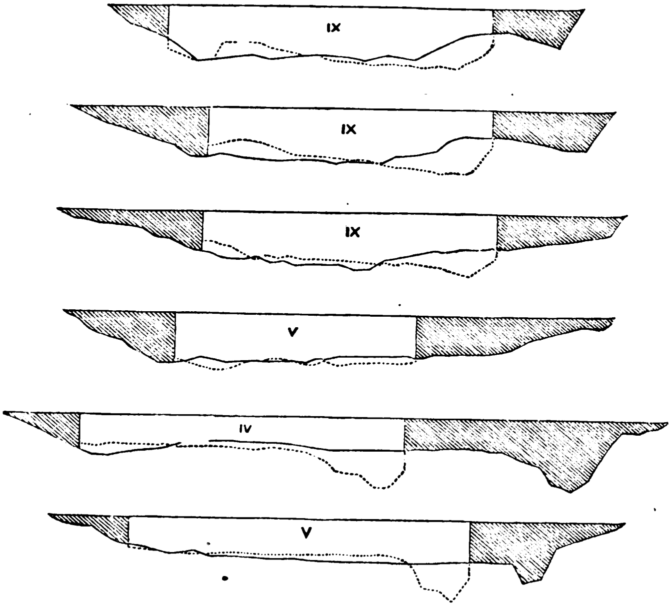


Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.

Sections projected to scale.

The above are some of the sections *projected to scale;* selected on account of their representing a fair average of loss and gain. In each case the shaded or lined portion of the section shows the lateral loss by works, the continuous line the old bed, and the dotted line the new bed between the points of contraction. Roman numerals are attached to each section, indicating the number of years the works had been carried out.

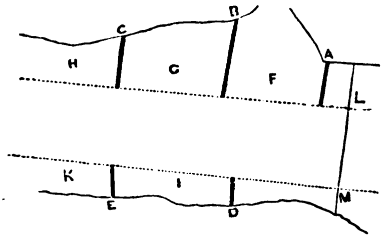
It must be observed, before drawing an inference from the foregoing facts, that the bed of the Tyne, being composed of a light shifting sand, is easily acted upon by every disturbing cause, and is continually varying in height. The effect of increased scourage upon such a soil would therefore follow *the first effort of the contraction,* and become immediately apparent; a case widely different from that of a river with a tenacious bed, requiring time and a wearing-down process to develope the full effect of improvement works. Here the question then arises, If scourage is commensurate with velocity, and the extra velocity in this case determined by the contraction, and extending over several years, has only restored one-sixth of the loss, is there anything in the future to alter this balance, and give an equivalent? If the least reflection be bestowed upon the subject, only one reply can be given: *As so little has been done, it is a proof, from the circumstances of the case, that nothing more will be done.*

The reader is also not to suppose that the amount under the head of 'Increase' in the foregoing Table is a gain in the navigable condition of the river; a glance at the state of the channel before and after the completion of the works, depicted on Plates A and B, will be sufficient to undeceive him; and that it is not so, will be further seen by the final balance we have to bring forward. It is only to be understood as having reference to sectional size between certain points, and to nothing more.

Again,—on Plate B, showing the state of the estuary in 1849, black spots are placed upon sections where, notwithstanding the reduction of width, *the bed of the river between the points of contraction is actually higher than it was in* 1813. Now, keeping in view what has been said in the previous chapter about the tendency of the beds of rivers to raise themselves, is it not probable, nay almost certain, that the shallow rather than the deep sections afford an index of what the future level of the whole bed will be?

To continue—The authors of the works in the Tyne consider that the completion of the scheme is necessary before effects can be determined; in other words, that the spaces between the groynes should be wholly instead of partially filled up and converted into land, and the river confined between straight and incorrodible boundaries. This leads us to the second part of the discussion upon the nature of the works, viz., *from what has been done to what is to be done.*

Fig. 11.



On referring to Plate B, it will be seen that land has only been formed in some of the spaces between the river works, the greater number of them being still open for the admission of tidal water. What effect has this admission on the general bed in front of the works? Figure 11 represents a portion of the river containing several of the jetties and unencumbered spaces. Owing to the use of breastworks, rubble walls, and other appliances, the stream of the ascending or descending tide has *now* a straight set along the outer extremes of the groynes A, B, C, D, and E, for the tidal water due to the lateral receptacles F, G, H, I, and K, is received and given off so imperceptibly as not to disturb the general current. The simple effect, therefore, of the obliteration of these recesses by their conversion into land will be, that less water in the same proportion will pass through the restricted section L M; and if therefore there be any truth in the law which we have already quoted, viz., "that the power of a stream in scouring a channel between certain points is in the exact measure of the quantity passing in a given time," it follows, in the case before us (for there is no avoiding the conclusion), that the bed of the river between the points L and M will rise in proportion to the loss of such quantity. The increase of section between certain points, indicated by the Table, is owing to the circumstance that the river, though possessing nearly its original superficial range, is forced to make a restricted effort; but when this is no longer the case, and the stream is really confined by solid shores between the lines expressed by the ends of the groynes, the consequent loss of tidal water will result in a proportionate loss in the depth of the channel, and thus the small compensation at present existing will in time be obliterated. Nay more, foreshores (as is invariably the case) will form in front of the completed boundaries, *and raise the bed higher than it originally was between the same points.*

It is needless to pursue the discussion upon the principle of alteration any further; for the facts speak for themselves, and are quite enough to place the system upon its proper footing.

We now turn to the general balance of loss and gain for the whole river, as it has a special bearing upon its navigable condition;—the important points are as follows:

1. The high-water line of ordinary springs (as in Rennie's day) was an exact level, while the low-water line was so slightly depressed as not to be a subject for consideration in determining loss and gain.

2. Of the 286 high-water sections between Shields and Newcastle, 69 had increased and 217 had decreased, being equivalent to a loss on a common spring tide of 34,261,000 cubic feet, seven-eighths of which loss was directly due to the artificial works between Jarrow and Hebburn. The above decrease of natural power is represented in a more simple form by a river a mile long, 500 feet wide, and 13 feet deep.

3. The effect of the increased scourage in the contracted river was confined to the higher parts of the bed, and did not affect the deeper gorge of the navigable channel.

4. Though 95 acres, or one-sixteenth of the high-water superficies of the river, had been converted into land, the isolated and principal sand-banks had increased from 99 to 104 acres.

5. The deep-water track or approximate sailing channel between Shields and Newcastle was practically of the same length at the two periods, but the average high-water depth in it had decreased from 25 feet to 24 feet 4 inches, while the channel of 1849, from being more broken, was more difficult of use for the general purposes of navigation. (Compare the two on Plates A and B.)

6. North Shields Harbour, containing the most important deep-water berthage in the whole river (including that for Government vessels, and which would be again required in the

event of war), had decreased 34 feet in breadth and nearly 3 feet in depth, while the throat of the port, or the space between the Low-light Beach and the point of the Middle Ground, had decreased from 30 to 40 per cent. in its low-water capacity.

7. Lastly, and as confirmatory of the loss of tidal water, to which it is in a certain degree a gauge of quantity,—the sectional capacity of the bar at low water, measured between similar contours, had decreased a quarter part, viz., from 9775 to 7560 square feet.

The material facts of the above comparison have for some time been before the parties directly interested, but hitherto without any useful result, for the same system is still being carried out upon the river, and even in an aggravated form.

Some light may be thrown upon the subject by referring to Mr. Walker's Report upon the River Tay, on the 21st of January, 1845. He says, "The injury done by any diminution of the power which scours the rivers and removes obstructions, *is not simply in proportion to the quantity abstracted; it is in a greater proportion:* that is, if you take away any, say half the quantity of the water that now keeps the river open, although by doing so you reduce the velocity only one-half, you take away much more than half the power. Every one used to canal or river navigation knows that very much less than one-half, or even less than one-fourth, the power is required to draw a boat or other body through still water, at one mile per hour, than at double the speed (the increase of power during the time it is exerted is as the cube); and also, which is indeed the same thing, that very much less than half the power is required to hold a body at rest against a stream which runs at the rate of one mile, than against a stream of two miles per hour. *And the same principle extends in a degree to the powers of rivers to widen and deepen their channel.*" The whole Report should be carefully studied, for it is very instructive.

No doubt the results already worked out in the Tyne are at variance with expectation, for the promoters of the works declare that they do not wish to reject tidal water; but if their system involves it, it in effect amounts to the same thing. It is said that "shoals are disappearing;" this would be well, were it not brought about by the curious process of forming land upon the top of them! It is said that "the channel is deepening;" it may be replied, that if this is the sole object to strive for, narrow the river by incorrodible banks to half its present width, and obtain at once the additional depth. *But depth is not the only consideration to be kept in view in improving a tidal river.* The tests we must apply to the system are these—*Have the same superficies been preserved? Is the depth at the loading berths fixed and self-sustained?* With provision for loaded and loading vessels, *is there an equal amount of stowage for light ones?* and with all this, *are there the same cubical contents of tidal water admitted into the river?* If this cannot be answered in the affirmative, it is quite conclusive.

As already remarked, the system of reduction has only been partly carried out upon the Tyne; when it has been completed to the extent indicated by the 'scaffolding' for the new shores, results will become more apparent in the diminished capacity of those parts of the river, which, from position, must receive the *full effect* of the aggregate loss, viz., Shields Harbour and the entrance. It may fairly be asked by the reader, if this presents the whole case; whether there is not some gain to set against the loss? Yes, there is a gain, and a very tangible one too, for it appears as tracts of land attached to estates on the banks of the river,—tracts extremely valuable for ship-building and other like purposes. There is, therefore, a present advantage in the system, *a natural and convincing rhetoric with many;* but on carrying the view forward, and seeing what the gain involves, these parcels of land appear as so many examples to prove by their ultimate effect that soil procured under such circumstances is purchased too dearly, *and that it is unwise to throw away the material properties of a river for any present advantage, however great.* This crippling ordeal is becoming increasingly felt in the state of the navigation; and as every new difficulty is met by an extension of the same system, it may safely be predicted that the time is not far distant when the authorities will understand that they have been employed in working out a theoretical mistake, but when, unfortunately, it will be too late to apply a remedy.

And yet this is a port of 40,000 annual arrivals and sailings, and the chief nursery for seamen in the north of England!!!

To specially apply the case to the subject of our theory.

Lateral reduction is really what the name implies, *a reduction;* and the effect is one and the same, whether the system be applied to the Tyne, the Thames, or the Dee,—for Nature is consistent, and will vindicate herself.

Lateral reduction does not improve the tidal propagation by raising the level of high water in the higher portions of the river, and is therefore *directly opposed* to the second theory of the preceding chapter.

Lateral reduction, while it is an inroad upon the superficial extent of a river, is also destructive of its power, by decreasing the tidal quantity, the ultimate effect of which has been seen in the examples quoted in the first chapter.

Lateral reduction truly has the effect of confining the river between narrower limits, *but it is no longer the same river,—it is a greatly reduced one; and instead of being the improvement of an original subject, it involves an entire transformation.*

Lastly, if lateral reduction *systematically* carried out is injurious, what must be the effect where proprietors are allowed to advance their foreshores at random, without any regard to the margin above and below them? It ultimately involves a greater comparative loss, and in the interim it inflicts a double injury upon the navigation.

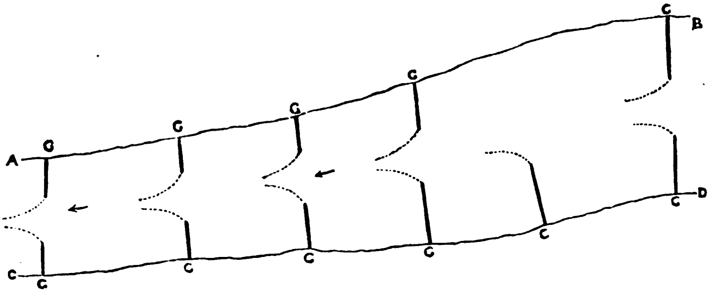
Paley remarks that "in all cases where the mind feels itself in danger of being confounded by variety, it is sure to rest upon a few strong points, or perhaps a single instance: amongst a multitude of proofs, *it is one that does the business.*" The example of the Tyne is a case in point. No hypothesis in favour of lateral reduction, however just in all its parts and skilfully worked out, can (in the mind of the writer) stand for a single moment before the facts which have now been detailed—facts which can be well sustained, and therefore refute all reasoning to the contrary.

All matters of mere detail have been studiously kept out of the foregoing description, but the Tyne case cannot be finally dismissed without a few words upon the works by which the alterations in the river have been carried out, and more particularly as to their effect upon the current and the adjacent bed.

Many of the transverse jetties upon the Tyne are very extensive, several of them (Plate B) reaching to a length of 700 feet or upwards, and extending nearly half-way across the stream. The *first effect* of the protrusion of such works across the passing current must be very marked; for whether it be the flood or the ebb, the stream is forced into the spaces between their extremes in a degree proportioned to the curved or straight character of the channel. Each groyne-end forms a point upon which the current incessantly acts: the filaments of the passing water are intercepted by it and turned athwart, and the effect upon the main stream is to confuse its action, and decrease its scour. Also, on account of the preponderating strength of the ebb over the flood (remarked upon in the preceding chapter), a hole, due to the increased action of the current, is invariably formed, *stretching obliquely downwards from the end of the jetty*, while the soil removed from it is generally lodged in the eddy a little below. Where jetties are regularly carried out on both sides the river and opposite to each other, their effect is felt over the entire section, *and the bed presents the profile of a waved line, with alternate deeps and shallows.*

The length of time which has elapsed since the works were first carried out upon the Tyne, accompanied, as it has necessarily been, by extensive silting between them, prevents our supplying an example of their primal effect upon the current; but the following one from the Tees, from actual observation,

Fig. 12.



and selected on account of the arrangement of the works, will convey the general fact of the deflecting influence of jetties. The example is from Billingham Reach, a mile or two above Middlesborough. The stream is that of flood. G G G, &c. are transverse wooden groynes, and A B and C D are the high-water boundaries.

The following figures represent the state of the bed in front of some of the more prominent of the Tyne jetties, though, from the modifying causes above mentioned, they are only to be regarded as the *remains of the holes which formerly existed.* In each instance figures are attached to indicate, in feet, the depth of the depression below the general surface near, while the opposite side of the river abreast each groyne is also marked, that it may be seen what proportion the hole bears to the entire breadth of the bed.

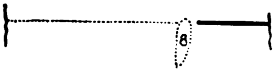


Fig. 13.

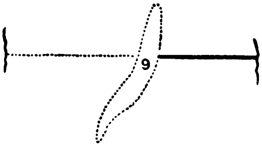


Fig. 14.

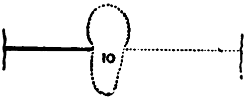


Fig. 15.

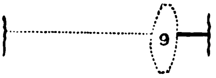


Fig. 16.

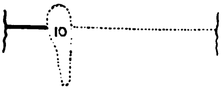


Fig. 17.

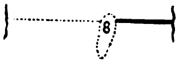


Fig. 18.

It is to be supposed that in sanctioning the use of jetties in the Tyne, the authorities were in ignorance of their effect elsewhere; if so, it is to be regretted, for Reports, condemning their use in the strongest terms, had been in existence for many years. They were at one time extensively used upon the Clyde, and Rennie, in his Report of December 24th, 1807, after their effect had been tried for near forty years, thus alludes to them: "In the channel between the jetties I generally found about a foot less water than at the ends of them; the channel is very narrow, and in many places crooked. *In fact, the principle on which the improvements are made is very deficient, and unless another mode be adopted, it will be impossible to render the navigation complete.* When the channel of a river is partially contracted, the water will no doubt become deeper where these contractions are; but what is removed by the current from the narrow places is lodged in the wider parts, where the current is more languid, and thus sand-banks and shoals are formed. These sand-banks may be in part lessened by means of dredging, but this is only a partial measure, for they will return in a short time after they are removed."

Smeaton, in his Report on Lynn Harbour in 1767, observes, "I entirely disapprove of all jetties built into the stream, *for they seldom fail of producing a deep pit either opposite to or on the downward side of the jetty.*" How true this is, may be seen by the Tyne examples.

Telford, in his Report upon the Clyde on May 24th, 1806, remarks, "The mode which has formerly been pursued of projecting jetties from each shore for a considerable way into the river, is, in my opinion, *a very imperfect and improper means of attaining the object in view.* The current of the flowing tide strikes upon the lower sides of the jetties in proportion to the velocity with which it is advancing, and its angle with the jetties; it by this means accumulates and forms a counter-current, which checks the velocity of the water which is next advancing, and not unfrequently crossing the general direction of the tide, meets a similar current from the opposite shore. (Refer back to fig. 12.) In the channel of the river, from the repeated contraction and expansion of its section, the water never can retain any uniform velocity."

Mr. Abernethy, in his Report upon the Dee, observes, "The effect of the groynes has been most injurious, impeding the tidal ebb and flow, and, what we think of more consequence under existing circumstances in this part of the navigation, diminishing the scouring power of the freshes, causing eddies and the deposition of detritus on their lower sides, which is again removed by the flowing tide and deposited in the channel, *the bed of which, from the great irregularity in the force of the current, is exceedingly irregular.*"

Smeaton's, Rennie's, and Telford's Reports were made before the adoption of jetties upon the Tyne; they have since been strongly condemned by various Engineers: the Admiralty Survey showed their effect in the Tyne itself, and yet an aggravation of the system is still persevered in upon this apparently fated river.

CHAPTER IV.

REMEDIAL MEASURES CONTINUED — LONGITUDINAL TRAINING — THE SYSTEM APPLIED TO A PARTICULAR CASE — THE FUNDAMENTAL LAWS OF RUNNING STREAMS, AND THE DIRECTION OF RIVER IMPROVEMENT FORESHADOWED BY THEM — TRAINING CONSIDERED IN CONNECTION WITH PERMANENCE OF CAPACITY — CURRENT REGULATION — FRICTION — SCOURAGE AND TIDAL PROPAGATION — SUMMARY REMARKS, &C.

THE writer now proposes to describe a system of amelioration, simple in details, certain in effects, and in exact harmony with the laws by which Nature is governed. The system is longitudinal training,—the converse nearly of that just described.

The term 'in train' has more reference to the movement of the stream than to the state of its bed; but, comprehensively speaking, a river as a whole may be said to be in train, when, *without any decrease in its quantity or any waste of its power*, it is forced by artificial means, during both flood and ebb, and in every variation of its volume, to conform to the same track, thus fixing, maintaining, and improving its channel, or, as it has elsewhere been pithily expressed, "instead of a feeble body of water, trailing over a maze of shoals, it is converted into a regulated and energetic current, made to do work, and to do it in the right place."

Several precautions are evidently necessary at the outset before any works are entered upon for the improvement of a river. First, that the whole of the phenomena of its bed and its tides throughout the tidal development should be studied and understood in connection; and secondly, that in making changes, and establishing as it were a new order of things, no works be adopted for the purpose, which, during their progress or upon their completion, will be opposed to the usual operations of Nature, or to her ultimate aim. In this way each river presents itself as susceptible of improvement, but the main features of which are still to be preserved; "for the velocities of their currents, and the direction of their courses, are in general so nicely adjusted, that it is only by a long and attentive observance of existing facts that we can presume to interfere with a process which has been in operation for ages." *Nature, in short, is to be assisted where she cannot do her own work, without her general arrangements being radically set aside.*

The system we have termed 'longitudinal training,' in so far as it can be described in a few words, *is the realization of the best possible navigable condition of the river, without the sacrifice of a particle of the tidal quantity.* Let us apply this system to a particular case, and then discuss its soundness in connection with several leading points, claiming by their importance the first consideration.

Plate C includes the same district of the river Tyne as that on Plates A and B; but all the detail, excepting the high-water boundaries of 1813, is rejected; and upon these are marked both the original and the additional shipping-places established up to 1849. The dark continuous lines, forming the outer limit of the banks or shelves, are guiding or training walls, reaching to half-tide. The transverse lines from the shores to the training walls are loading staiths or jetties, upon stilts or open pile-work, opposing no interruption to the passage of the tide. Collectively, the general design of the works is to make the bends more gentle, and the reaches as equal and uniform as is consistent with their natural shape; and to effect this with the least possible interference with the original capacity of the river. Then the space of deepest blue between the training walls represents the form the channel would probably assume when the effect of the works, aided by dredging, was fully developed. Any other information as to design is contained upon the Plate itself.*

The principal fundamental laws of hydraulic motion which

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* The training walls, being regulated by the form of the reaches, do not give loading berths at all the shipping staiths at present established, and which have been run out from time to time to reach the casual deep water of the river. Their permanent places would be between the boundary letters A A, B B, C C.

have been fairly established, and which in their nature are specially applicable to river improvements, may be verbally expressed as follows:

1. The motive power of running water is gravity, and the motion of rivers entirely depends upon the slope of their surfaces.

2. The resistances to the downward movement of a stream proceed from the form and nature of its bed; the friction of which, acting upon the viscidity of the water, is communicated to the whole mass. Hence, as a general proposition, a decrease of friction implies an increase of velocity.

3. When a stream runs uniformly, the sum of all the resistances is equal to the accelerating force, and they are said to be in equilibrium; or one is the exact measure of the other. Under these circumstances the accelerating force is equal to the weight of the body of water in motion, multiplied by the fraction which expresses the slope.

4. The velocities are nearly as the square roots of the depths. In small velocities, the velocity in the axis (or centre of the stream) is to that at the bottom in a ratio of considerable inequality, but this ratio diminishes as the velocity increases, till, in very great velocities, it approaches to the ratio of equality.

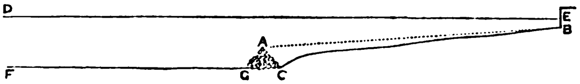
5. When the sections of a river vary, the quantity of water remaining the same, the mean velocities are inversely as the areas of the sections.

6. The mean velocity of a stream upon any one section is the arithmetical mean between the velocity at the axis and that at the bottom. To find the bottom velocity, take unity from the square root of the superficial velocity, the square of the remainder is the required velocity. Thus, allowing the velocity in the centre of the stream to be 16 inches per second, its square root is 4; reject unity, and there remains 3; the square of this is 9, the velocity at the bottom; then $\frac{16+9}{2}$ or 12½ inches per second is the mean velocity. Generally speaking, the mean may be assumed at four-fifths of the velocity in the axis.

There is also another prominent law, but to which we shall have to take exception in the sequel,—it is as follows: It is the velocity of the filaments of water in contact with the bed which produces any change in it. Every kind of soil forming the bed of a river has a certain velocity consistent with the stability of the channel. Thus, a velocity at the bottom of 3 inches per second just disturbs fine clay, while one of 36 inches per second will sweep along angular stones of the size of an egg. With a river then in what may be termed working order, the current is in equilibrium with the size and form of the channel, and with the tenacity of the bed.

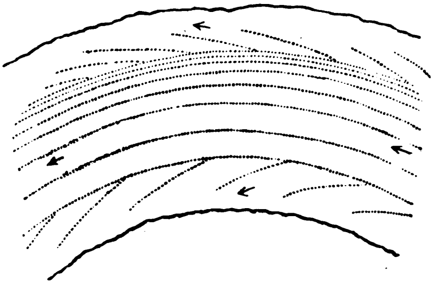
There are several secondary laws of motion springing out of the foregoing as a groundwork, but on these we need not dwell. Each law, as above stated, is easily understood, and as far as they collectively indicate the principle of river improvement, *they point to a decrease of friction, an increase of capacity, and a concentration of power*, as realizing the best conditions in the mutual action of the current and its bed. We shall now show briefly how far these and other desirable objects are compassed by the system we have propounded.

Fig. 19.



Permanence.—Figure 19 represents a transverse section of one side of the trained stream, with D E and F G the high-water and the low-water surfaces. Allowing the training wall to be placed near low-water mark, then the triangular space A C B between the original flat and a line joining the inner part of its surface with the top of the training wall will speedily silt up by the deposition from the penned water, till the alveus presents a regular escarpment from wall to shore, as A B. That it would then be permanent needs no proof in addition to that supplied in Chapter II. It is usually urged by Lateral Reducers, in vindication of their peculiar system, that the conversion of these lateral spaces into land is only a matter of time; but if, as we have shown, there are many examples of permanency of level, even in flats entirely recessed, may we not fairly assume that there would be a guarantee for fixity in these spaces within the walls? A current would be constantly setting over them while covered during the flood and ebb, and upon no part of them could the water be in a state of entire stagnancy; while the addition of their breadth to the general expanse would supply an extra power to the action of the surface wave to insure their maintenance. This point has been so fully explained under the head of 'Theories,' that we shall not enlarge upon it here, but consider it established, that land would not accrete in the lateral spaces after the escarpment was once formed.

Fig. 20.



Current Regulation.—As the channel of the river would be between the training walls, so would the current be till half-tide—the time of their covering. We learn from the fourth fundamental law of running water, that "the velocity of a stream is in proportion to the square root of the depth," or (what will answer our purpose as well) the greater the depth, the greater the velocity. Hence it follows, that as the greatest depth would *always* be outside or between the training walls, so there would be the greatest velocity; and arguing from analogy, we can be at no loss in understanding that during the whole time of their submergence the walls would determine above them well-defined boundaries between the strong current of the channel and the weaker current of the flat; the latter gradually decreasing with the decrease of depth from the walls to the shore. The whole of the filaments of the current, in short, would be brought into a series of gentle curves harmonizing with the general direction of the walls; and instead of being stopped and thrown off, thus impairing the combined effect, they would glide gently by, with the least interruption possible. This action will be better understood by referring to figure 20, where the stream for the lateral space is represented quitting the main current by easy diverging lines. The same relative movements reversed would take place upon the ebb: in either case the amount due to the sides of the tidal basin would be given off or received without disturbance, while the flats, being smooth and sloping, would offer nothing to take hold of, and entangle the current.

Friction.—The friction, or the resistance to the motion of a stream (as already observed), proceeds from the form and nature of its bed. Every irregularity, whether natural or artificial, acts as an interruption. The resistance of each to a current of any force is considerable, for the passing filaments are deflected, causing eddies and cross-sets, and in every case where the stream is forced to deviate from a straight line, there must necessarily be a destruction of momentum. We see therefore how important a point it is that the bed and sides of a stream should be well regulated. It will be observed that the walls on Plate C are continuous, easy, and natural, following the general course of the reaches in *gentle bends,* and offering no irregularity for the current to take hold of. Each concavity determines a decided impact against itself. There can be no rebounds, for there is nothing to generate them, while the principal strength is preserved in a *fixed axis* in every reach.

During the submergence of the walls, the friction would also be less than if solid and impervious barriers reaching to full tide (as in lateral reduction) occupied their places; and for this reason,—as friction results from the adhesion of the water to the bed in which it moves, it follows that the friction of a stream against a fixed wall would be greater than if it were confined between equally distinct boundaries, which, instead of being fixed as in the former case, *moved at a slower rate in the same direction as the stream itself.*

Scourage.—Before touching upon the improved scourage upon the bed of the trained river, we may offer a few words upon the cause of the formation of shoals, though they scarcely require a separate consideration; for that which regulates the current and decreases the friction, must also act upon the bed, remove obstructions, and thus bring it into a state of regimen.

The beds of rivers are shifting and fluctuating, and variously composed of sand, gravel, clay, or rock, according to the geological character of their district. We described in a previous chapter the superior width of the estuary compared with the other portions of the river, a feature resulting from various causes; among which may be included as the principal, the opposition of the two currents, tidal and fresh, with the consequent increase of lateral action, and also from the effect of the wave due to the size of the expanse. Each of these operations adds to the mass of sand and other matter brought down from the interior into the body of the estuary, the principal deposit of which is at the sides, for there the current is weakest. The process of winding facilitates the formation of central shoals, for when the sand below a point usurps to some extent a portion of the channel, the flood stream, in seeking to avoid the obstruction, creeps up within it, and thus isolates it. The current of the river, in this its natural state, must needs be as irregular as the bed itself; for every obstruction disjoints it, causing innumerable eddies and dead water, in which fresh deposit rapidly takes place, to be shifted again from spot to spot with every change of the current. Sand collects about the least nucleus, or falls directly the current is relatively quiescent; in a few years the crest appears above water, and as it increases, it excludes a quantity of tidal water from entering the river more than equal to its own bulk. It is evident that a channel through a bed thus constituted has none of the elements of permanency about it; it is not only rendered difficult in proportion to the number and extent of the obstructions, but it is also liable to be wholly broken up, as we have seen was the case with the Tyne in 1771.

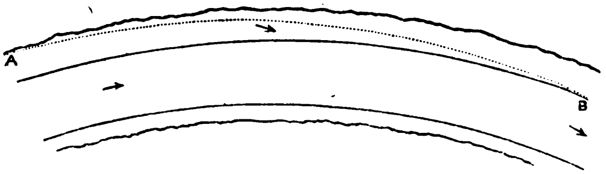
The first establishment of training walls would meet the greater portion of the above evils, for as the main current must necessarily be between the walls, *the region of shoals would be reduced by about one-half.*

This leads us to the question of scourage, or rather to the *exact time of its maximum effort.* This is a subtle point, and one of the utmost importance, but which nevertheless is still a matter of the purest conjecture, resting solely upon individual opinion unsupported by experiment. How common is the remark, "Such and such a body of water is of no use in preserving the channel, as it goes off with the first turn of the tide;" an assertion which is habitually regarded as a fact, without any attempt being made to test its soundness. A little reflection, however, would show that it is a *compound question* —hydrostatic as well as hydraulic, depending upon the two elements of *weight* and *velocity,* and hence it is a very difficult matter indeed to determine when the greatest scourage really does take place. The above view is somewhat shadowed forth in Mr. Rendel's evidence upon Birkenhead, where he remarks, "The greatest scouring power over the Victoria bar is at the time when the quantity of water is the greatest and the velocity greatest, so that the quantity multiplied by the velocity (momentum) is the greatest." This is quite consistent with fact; for why, we may ask, is the bed of a large stream deeper than that of a small one? Not on account of velocity only (as the law we have quoted would seem to convey), for it is very possible the rate of the latter is double that of the former. It can only, therefore, proceed from the circumstance, that with the velocity there is another element of quantity, or *weight,* in addition, whereby the larger stream is enabled to maintain a channel of a depth proportioned to its magnitude. In short, fluids and solids are subject to the same laws of gravity, with this difference, that the particles of a fluid move *inter se,* which the particles of a solid do not; but this exception is limited to the relative movement of particles only, and does not apply to the effect of the gravity of the mass. To put a parallel case with a solid: if upon a yielding soil we drag along a light body at a certain rate, it leaves no impression; but if we double the weight and reduce the velocity one-half, it will leave a furrow. There is no physical reason why this example should not apply to the case of a fluid as to its action upon the soil to be moved by it, *and it is very possible that a deep stream moving slowly may have a greater scouring power than a shallow stream moving quickly.*

This point has a most important bearing upon the enclosure of indents. Allow, for example, that the higher portions of the bed covered only at spring tides are so enclosed, and that a compensation as to space is given for it, either by the removal of the foreshores in front or by lowering obstructions in the channel; there will accordingly be more tidal water thrown into the river at the early, and less at the latter portion of the flood, and of course less will be returned during the early portion of the ebb. There will be the same quantity of tidal water in both instances, but the portion gained may, after all, be no *real compensation* for that rejected; for if the greatest scouring effort is at the latter flood and early ebb, it is very possible that the portion enclosed *was just that portion which supplied the weight for friction at that moment when the scour or mechanical action on the bed was the greatest.*

In the absence of certainty, however, *the only safe view evidently is, to consider every particle of tidal water which enters the basin as useful for scourage, either in one condition of the tidal column or another, and rigidly to preserve it.*

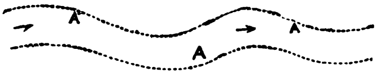
Fig. 21.



Apply the above to our system. A particle beginning to quit the flat at A (fig. 21) at the first turn of the tide, and allowing the common rate of current and fall to exist, will, by the time it has arrived at B, say 3 miles lower down, have receded from the flat altogether by a regular converging line, and joined the main stream. So would it be throughout the whole extent of the tidal basin. Each particle contained in the lateral shelves of the trained river would, on the receding of the ebb, join the main current either at one place or another, and thus add to its momentum and scour.

Again.—We have said that training walls reduce the region of shoals by one-half, the power of the stream being thereby concentrated, and forced to act upon a limited width instead of being diffused, and its force spent over a greater surface. The soil of the regulated bed—first the superficial formations, and then the harder subsoil—gives way before the increased velocity without the walls, and in exact contradistinction to the river in its natural state, *the current works to obtain in depth what it finds it cannot obtain in width.*

Fig. 22.



It may be added, that the presence of a fresh or flood would scarcely disturb the general action. The main effort of the scourage would still be in the same axis, for it must perforce obey the impulse as to direction communicated by every concave. The only difference would be, that while the fresh lasted, a somewhat increased abrasion would be produced upon the *lower sides* of the channel in every instance, as at A A A, fig. 22; but these boundaries would again assume their usual form after the subsidence of the flood.

Tidal Propagation.—This brings us to the last subject of practical importance to be discussed in connection with the system of training, and upon which it is proposed to dwell at some length, viz., the tidal propagation in a river, and the causes by which it is influenced. As a necessary introduction, we must first understand the modifications of tidal motion in the sea, for like causes produce like results in the sea and in the river. These are resolvable into two principal operations, which we term *gorging up* and *throttling.*

The oceanic tide undulation, due to the joint influence of the moon and sun, is a wave of great extent, travelling at a varying rate, possessing also the property of giving the water a progressive or horizontal motion. The velocity of the crest of this wave in the ocean, measured by the successive times of high water at different stages, has been estimated at 500 miles per hour, while in confined seas and channels it is reduced from 70 or 80 to as low as 15 or 16 miles per hour, and in rivers where obstacles are multiplied, from 20 to 4 or even 3 miles per hour. The rate of the *tidal current,* due apparently to the action of gravity upon the incline presented by the tidal *wave,* also varies considerably, being dependent on the form of the shore by which it is bounded. The mean rate may be estimated at 2 miles per hour, while round many of the headlands upon the British coast it is very considerable; for instance, the tide from the westward round the north of Scotland rushes through the Pentland Firth at a rate of 7 or 8 miles per hour, but when it again diverges into open water its strength abates, and it resumes its usual motion.

Upon a plain coast, both the height of the crest of the undulation and the rate at which it travels may be assumed as uniform; but this is altogether altered in straits and narrow seas, for the height of the wave depending upon the configuration of the coast, the water *piles itself* against some shores, and not against others. The undulation is sometimes influenced in this way to a remarkable extent. We see a singular instance of it in the Bay of Fundy, where the tidal wave, ranging from south to north along the American coast, is intercepted in a hook as it were, and *gorges up* to the extraordinary height of 100 feet. On the shores of Great Britain the phenomenon also exists in a minor degree. The wave intercepted in the opening between the Land's End and Cape Clear, and directed forward by the general 'trend' of the coasts towards the *converging shores* of the Severn, *and having no outlet*, rears its crest 30 feet at Swansea, 40 feet at the Avon, 50 feet at New Passage, and 60 feet at Chepstow; while on the opposite coast of Ireland the rise is not more than 4 or 5 feet in one place. In the same way, in its progress up the English Channel, the tide lifts 7 feet at Portland, 15 feet at Selsea Bill, and 20 feet at Dover, where, had there been no strait, the elevation would probably have rivalled that in the Severn. The wave in filling the head of the North Sea Basin rises 7 feet at Yarmouth, 12 feet at Harwich, and 16 feet at Sheerness. The foregoing instances are sufficient to show the particular effect the *form* of the coast has upon the height of the undulation.

The reason for the phenomenon seems obvious. If, for instance, we partly fill with water a trough having (like the above examples) sides converging to a point, and make a slight undulation by hand at the broad end, then, as the wave moves along the trough, it will gradually increase in height, till at the head it will rise still higher, and even dash over in a spray.

So with the tide wave: that portion intercepted between two capes or points proceeds up a gradually narrowing channel; as it advances, its momentum is preserved in a great degree *by the sustained pressure* of the larger body of water behind it moving in the same direction, till, at the head, from having no escape, it is thereby forced to a higher level. The declination of the bed also adds to the above effect, which will be greater or less in proportion to the convergence of the shores, to the impetus of the current, and according as the receptacle to be filled is, or is not, in the line of direction of the *initial impulse* of the wave itself.

While considering the phenomenon of *gorging up,* we must not omit a passing reference to Lynn Deeps,—another instance of the sort, for the case affords one or two points of present interest. The wave approaches the Wash at the rate of 70 miles per hour, and its height increases from 19 feet at Spurn Point to 24 feet in Lynn Road. From the roadstead up to the town of Lynn, although the space is much encumbered by sands, the rate of the crest of the wave is still 40 miles per hour (about double that of the best conditioned of our estuaries), and the tidal current, increasing gradually from the road to the town, rushes through Lynn Harbour at a speed of 5 or 6 miles per hour, or double the rate of the ebb, though aided by the land water. Smeaton, who was called in to report upon it, terms it a "raging tide." There is, in fact, a *heaping up* at the mouth of Lynn Harbour from its being at the exact head of the Wash, and which heaping up and consequent pressure produces the superior momentum. Whenever, as in this case, there is a connecting channel between two wide expanses, there will the current be found to run with the greatest velocity; and Lynn Harbour in this respect is somewhat in an analogous position to the deep gorge at Liverpool—to Broughty Ferry—Yarmouth Harbour, and many other cases of a similar character. Here a distinction must be borne in mind. The reception of the tide into a receptacle like the Ouse is essentially different to that of a river opening out at right angles upon a plain coast: in the latter we have shown that the supply is regulated by the capacity as a receiver, while the Ouse obtains a quantity *over and above this,* from the river being in the direction of the tidal impulse.

Such hitherto has been the advantage of position to the town of Lynn, for to this circumstance of superior tidal quantity and energy is mainly owing the depth of the channel of the Ouse abreast the town. Lately, however, the inhabitants have aided a proposal embodied in the Norfolk Estuary Bill, having for its special object the conversion of 32,000 acres of the head of the Wash into land. With this view, it is proposed to forsake the present channel of the Ouse below Lynn, and to substitute for it a cut 10 miles long, extending in nearly a straight direction from the town across the marshes through the sands, and down to Lynn Road,—an arrangement which it is assumed will be equally beneficial to drainage and to navigation.

Fig. 23.

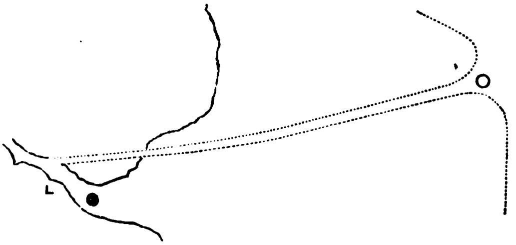


Figure 23 represents the circumstances of the case. The continuous lines are the present high-water shores, and the dotted lines those of the proposed cut. The black circle indicates the present position of the tidal pressure while generating a momentum to the flood stream, and the open circle where it is to be removed to. L is the town of King's Lynn.

If the scheme be eventually carried out in its entireness, *as it appears on the parliamentary plan*, the following effects may be predicted:

1. The head of the Wash, instead of being at the town of Lynn, will be at the entrance to the New Cut.

2. The rate of a current is determined by the sum of *all the resistances.* Therefore, the initial velocity of the flood stream, or that generated by the *gorging up* at the mouth of the New Channel, will be gradually reduced by friction as it advances

upwards, till at Lynn its momentum will be considerably diminished, and it will pass the town as, comparatively, *a spent shot.* Hence, as *less* tidal water will be thrown into the Ouse, there will be a corresponding loss of scouring power on the return of the ebb.

3. The straight cut would be inferior to the present channel for navigable purposes, and for this reason,—the centrifugal force brought into action by a succession of easy curves must needs lower the channel *as a whole* to a greater extent than would be the case in the straight cut, where the bed would be comparatively uniform and shallow.

4. The question is one of drainage also. We have said that the tide rises higher in the upper reaches of the Ouse than it will do when the scheme is carried out, and so far the latter condition would appear favourable to improved drainage under ordinary circumstances; but there is another view of the question to be taken into consideration. *The simple effect of the works will be to remove the ultimate level* (the sea) *from the district to be drained* 10 *miles at high water, and about three-fourths that distance at low water.* We have already learnt that the resistance offered to the escape of a flood is at the surface exposed to its action—that is, as the wetted surface multiplied by the length of channel; *length therefore is a main element of resistance,* and here the question arises, *will an escaping flood not have to rise to a greater height to overcome the increased resistance of a lengthened channel, than it now does to surmount the superior head of tidal water?* In the absence of minute details, we do not give a reply; but the subject claims the most serious consideration.

5. Lynn would be deprived of the inestimable advantage of an outer roadstead, for the sands must necessarily dispose themselves in front of the intended works in such a form as to afford no shelter—a point involving more than the loss of property.

6. It is very possible that the execution of the first stages of the work may be unattended by any inconvenience; effects would only be fully apparent as the scheme advanced towards completion.

Lastly, Stripping the case of all those conflicting statements and opinions by which such schemes are generally accompanied, *the actual result of the measure will be to place Lynn* 10 *miles further inland;* and what this involves is no matter of mystery, for, generally speaking, the relative value of any shipping place (locally considered) is in exact proportion to its vicinity to the sea. The measure is the more to be regretted, as the present channel of the Ouse is remarkably susceptible of improvement at an inconsiderable outlay. Lynn, as we observed in a former chapter, is fated to lose her character as a sea-port from natural causes, but it scarcely consists with true wisdom to hasten on the evil day.

Leaving this digression, and reverting again to the phenomenon of *gorging up*. It can be scarcely necessary to remark, that as Nature is not governed by different laws in similar cases, that which exists in the major example of the sea, will also co-exist in the minor example of the river. We see this to be the case in the Thames, where the tide at London rises 2 feet higher than at the Nore; and in the Humber, where the level at Hull is 2 feet higher than that at Spurn Point; effects arising from exactly the same cause, viz., the trumpet-mouth condition of their entrances and their inclined shores; or, as it might be otherwise put, the preponderance of the width of the entrance over the size of the receptacle to be filled.

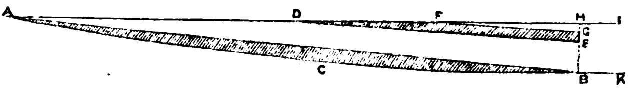
This superior level is frequently held forth as one of the most prominent objects of river improvement; but we now proceed to show that where it does not exist naturally, it is not to be produced artificially. Take the river Thames as an instance. Here the most extensive alterations have been made, and all in the direction for producing the effect; that is, while the mouth has been preserved of nearly the same form, the river above has been considerably narrowed; and yet Mr. Walker observes, "The artificial embankments have not produced much effect upon the positive height of the water," and in another place he states his belief that the level is lower than before the embankments were formed. Alan Stevenson remarks upon the Tay improvements, "The tide does not rise much higher—I think hardly at all." It may be asked indeed, why should river improvements have such an effect? Assuming, for the sake of argument, that an increase of velocity would be followed by an increase of height, how is this increased velocity over the whole stream to be obtained? It is said, that by removing shoals from the bed of the river there is less obstruction to the progress of the tidal wave—that its momentum is thereby increased, and that it will rise accordingly to a higher level. Now, the rise of tide in the lower portion of an unimproved river is far more rapid than its propagation; for the obstruction offered by shoals and other irregularities to the progress of the early flood increases the head or difference of level between the sea and the higher reaches of the river, but directly the impediments are overcome by the continued rise, and the tide 'let free' as it were, then the rise and rate, especially during the latter portion of the flow, is very rapid. River improvement works, on the contrary, by lowering the bed and allowing the tide to be propagated at an earlier period, have the effect of *equalizing* the rate throughout; and though more tidal water is admitted by such depression of the low-water surface, still, as the larger quantity *has a larger channel to pass through*, its rate as a whole cannot well be accelerated. The improvements in any river, judiciously treated, must also bear but a small proportion to the whole section when the river is full, and the river in its improved condition be after all a slight modification only of the river in its natural state. Not only so, it is very possible, on account of the earlier propagation, that the current may run slower near the time of high water than it did before the improvements were entered upon.

The superior high-water level has sometimes been assumed as following river operations on the principle, that the relative motions of the high and low water surfaces of a river are akin to those of a pendulum; and that if the low water be depressed, it must have the effect of elevating the high water to a like amount. Surely there is no parallel between the cases! Each vibration of the pendulum gives the law to the succeeding one, and the arcs of the vibration on either side the perpendicular are identical; but, however plausible such an idea may be as to the undulation in the open sea, gravity alone would prevent any mid-tidal line of the river taking the place of the perpendicular of the pendulum.

The other phenomenon to be noticed, and which we have termed *throttling*, is exactly the opposite of the preceding one, and results from exactly opposite causes. It is seen in several instances in this country, but more particularly in the Tay and the Yare. These estuaries are of the pouch form, with contracted mouths; and the orifice of each not being large enough to fill the interior basin before the undulation subsides, the high-water level of the river does not rise so high as that of the sea. This evil is to a certain extent susceptible of remedy, for if the throat of the Tay at Broughty Ferry was widened, there would be more water over the sills of the docks at Dundee, and a better flow in the higher parts of the Tay; and if the narrow channel of the Yare through Yarmouth was opened out, there would be a superior tidal lift in Lake Breydon and at the towns above it, while the return of the additional quantity would improve the outlets in both cases. It is unnecessary to dwell longer upon this point—what has been advanced respecting the two marked features of tidal motion is sufficient to show what an important influence the condition of the orifice of the entrance has upon the whole quantity of tidal water thrown into a river.

To sum up under this last head. It has been explained, that in carrying out river improvements, the high-water level is to be accepted as nearly a fixed point, not to be materially influenced by river works: the low-water level, on the contrary, inasmuch as it depends upon the state of the river bed, is to be acted upon by the means pointed out; its depression insuring an increase in the tidal duration, and hence of the tidal quantity;—the first, all-important as affecting the interior navigation; the last, equally so in the maintenance of the entrance. The nature of the gain or the difference of the tidal contents is indicated by the lined portion of the following figure, where A B and A C B represent respectively the low-water surfaces before and after improvements; A D E, the

Fig. 24.



original high-water surface at the time of high water at the head of the river, and A F G, the corresponding high-water surface of the improved river. H I and B K are the high-water and low-water levels of the sea.

We have now considered the system of longitudinal training in connection with the several important particulars of permanence, current regulation, friction, scourage, and tidal propagation; but the following closing remarks will not be out of place.

1. Accepting the rate of the tidal propagation as a criterion of the condition of the receiver, the progress of the early flood is a test of the state of the bed, while that of the latter flood and crest of the wave are equally so of the foreshores and margins.

2. To avoid the evil of an increased fall at the head of the tidal river, which would invite the gravel of the upper course to move lower down, the tidal flow should be the limit of remedial operations.

3. Improvements should begin from below, because that part of the navigation is more generally important, and rivers have also been greatly improved at a distance from their confluence with the sea by simply deepening their outfalls.

4. *Every portion* of the alveus of a tidal river is valuable as a receptacle, in whatever part of the river it may be situated. The first operation of the flood is somewhat like that of a wedge, creeping up under the descending land waters, and elevating them, till, as it opposes greater resistance, it dams them back, and then reverses them, making high water in the upper course of the tidal river by the reversed action of the land water. Thus, in the Thames (and which applies more or less to other tidal rivers) the salt water at high-water springs ceases at Greenwich, and yet the flood runs strongly past London and continues to Kingston, 24 miles above it. It follows, then, that the larger the expanse at the head of the

river for the fresh water to spread itself into, the less space it will occupy in the main channel, and more tidal water in the same proportion will enter the channels below. And so with every part of the estuary: *not a fraction of the quantity is useless;* for though the precise particles above a certain distance from the sea may not reach the outlet, yet they add to the momentum and scouring power of the whole of the intermediate stream.

5. Straight reaches *are strictly to be avoided*, but more particularly where there is an established business upon the banks of the river to be trained. With a straight reach the deep-water track is acted upon by the most trifling causes, ranging from side to side at will; and it follows that, under these circumstances, there is no security whatever for the permanency of the deep water, either in a fixed channel or at the shipping berths.

6. Dredging should go hand in hand with the formation of the training walls; first, to prevent the soil being scoured from the shallower into the deeper portions of the navigation, and next, to break up the indurated crust of those ancient shelves or banks which are so firmly bound as to resist the improved energy of the current. *Dredging, as a system, is an error in principle; it is an attack upon the effect rather than the cause;* but as an adjunct in the way we recommend, it may be essential, as it aids Nature in the attainment of that permanency which is the aim of her properly directed operations, but which she cannot in some cases arrive at unassisted. When the river has been fully trained, and brought into a state of equilibrium, dredging would only be occasionally necessary here and there for the removal of a casual obstruction, as the stream would then be comparatively in a self-sustaining state.

7. While the training walls are being formed, the natural shores should be straightened and defended, to prevent their wastage adding to the moveable matter in the tidal basin.

8. Entrances to docks *within the natural shores* might easily

be appended to such a system without breaking the unity of the design, or interfering with the action of the stream.

We will only add to what has been offered rather as a sketch than a detailed description of the true principle of river improvement, that, as a system, it is entirely consistent with Mr. Scott Russell's idea, that "it is possible to obtain a good deep rectangular channel for the progress of the tidal water way, and at the same time to keep unimpaired the whole lateral area for the reception of the tidal water." Though the precise *modus operandi* may not have been hit upon in that now proposed, yet the system considered in its entirety we believe to be sound; it involves no radical changes, and is in exact concert with the laws by which Nature is governed. One of the great advantages of such a system well understood would be, that each stage in the progress of improvement would be complete and *final*, producing possibly a fractional effect, *but still an effect in perfect keeping with the ultimate whole.*

The only practical difficulty in the plan we have propounded would be, so to arrange the position and depth of each concave *that it should determine a fixed axis of effort in the direction of the succeeding and opposite one*, or, to make use of a simile which will be readily understood, to arrange with precision the angles of *incidence and reflection;* but a close approximation might be made either by observing other examples, or by experiment, before the works were begun.

These views result from the matured conviction of years, and it is pleasing to know that they have in part been carried out on several rivers by the Messrs. Stevenson of Edinburgh, and with the best results—results not only flattering to the professional reputation of those Engineers, but which are also most encouraging, as showing that river improvement is a matter of certain accomplishment by a steady adherence to correct principles.

CHAPTER V.

BARS — THEORIES ACCOUNTING FOR THEIR FORMATION — APPARENTLY DUE TO THE WAVE-STROKE — NATURE OF THE OPERATION — EFFECT OF THE CONFIGURATION OF THE COAST UPON THEIR EXTENT AND CHARACTER.

PIERS — WHY PROJECTED.

CONCLUSION — CLASSIFICATION OF SYSTEMS — THE FACT OF HARBOUR DECAY, AND THE IMPORTANCE OF A TRUE THEORY.

STRICTLY speaking, the consideration of the comparative powers of a tidal river and systems of improvement terminates with the last chapter; but we must not conclude without a brief reference to the outlet, and its important connection with what has already been advanced.

The principal obstruction at the mouth of a tidal river is a bank or bar stretching across the entrance from point to point, and generally of a crescent shape, with less depth upon it than in the channel within it. Bars are chiefly composed of detrital matter, such as sand or small gravel, and are subject to fluctuations in height and position. They do not exist in all river outlets (though the exceptions are but few), neither are they all of the same character, the reasons for which differences will be hereafter explained.

Numerous theories accounting for this feature have been propounded, but the following are most deserving of notice:

Firstly. To the current from the river becoming inert at its junction with the waters of the sea, and there depositing the matter held in suspension.

Secondly. To the flood and ebb streams running in different channels.

Thirdly. To ground waves (*flots de fond*), which, during tempestuous weather, lodge sand within the entrance.

Fourthly. To a sub-marine contest between the first of the sea flood and the last of the river ebb, whereby the latter yields up the matter it holds in suspension.

Fifthly. To an insufficiency of back-water for removing outer obstructions.

Sixthly. To the action of waves in piling up detritus upon the shores in the direction of their greatest force.

The last of the series emanates from Sir Henry De la Beche, and it appears to contain an explanation of the feature, though not exclusively so. We propose to confine the remarks we have to offer to those examples with which we are most familiar, taking care, that although they may not in all cases account for their appearance, they are at the least not inconsistent with it. By thus adopting examples where all the circumstances are fully known, we avoid misplacing or exaggerating a few minor facts, to the neglect of others more important.

A wave has been defined as "a motion of the particles of water in a circular or elliptical orbit, arising from two forces; the one being that of gravity, and the other the force of the wind, or other motive power causing the wave." It was long a prevalent belief (and one not yet exploded) that the water advances with the speed of the wave, whereas the *form* only advances, while the *substance* remains rising and falling in the same place. That this is the case, any one may convince himself by visiting a ship at anchor in a calm day and at slack tide. If there be a swell setting in towards the shore, and a chip or other buoyant substance be dropped overboard, it will rise and fall with the undulation, but it will remain near the vessel for a considerable period. The slight forward motion it acquires towards the strand is not that the water itself is moving in that direction, for if the eye be placed close to the surface it will be observed, on looking downwards, that the particles of suspended matter are stationary: it arises simply from the gravity of the chip or other substance becoming active upon the steep descent presented by the front of the undulation. Gravity has exactly the same effect upon the vessel, inclining the chain a little from the perpendicular; or if she be under weigh, and though it be a dead calm, it will impart to her a slight progress through the water; she will 'forge ahead,' as it is technically termed. This fact of the simple undulatory character of the wave of magnitude has a most important bearing upon the founding of walls in deep water for the purpose of refuge or other harbours; for it shows very clearly *that the mass of the wave would be a mere oscillation in front of an upright wall so placed*, and that the stress upon a work of the sort would be confined to its summit, which would be exposed to the stroke of the surface drift only.

Even up to the present day the mechanism of waves is but imperfectly understood, more especially as to their maximum height, the rate at which they move forward under varying circumstances, and the depth to which their action extends below the surface. We shall devote our attention to the last point, as it is the only one applicable to the subject.

The following facts appear to favour the opinion that the influence, and even the *propelling power*, of the surface wave is felt at a considerable depth. During the late survey of the North Sea, and when, in connection with the projected refuge harbours in the Channel,* much interest was excited about the movement of shingle, not only as to its progress along-shore, but also as to the source from whence it was derived, opportunities were taken advantage of for testing the nature of the bottom in the offing abreast the Suffolk coast, where extensive shingle beaches are situated, and it was found that shingle ridges existed a few miles off-shore, disposed in a direction somewhat parallel to the main. The material was exactly the same as that forming the beach, viz., small flint, and more opaque than that procured from chalk; the only difference between the shingle of the ridge and that on the shore was that the former was rather more angular. In sounding the intermediate space, the arming of the lead commonly brought up sand, *but occasionally a pebble*, and the idea it conveyed at the time was, that if it had been possible to uncover the bottom of the sea, it would have presented the appearance of a sandy waste with single pebbles scattered over it—travellers, as it were, from the ridge to the shore. If this be the case, the

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* In 1844 the writer gave evidence before the Harbour of Refuge Commission,—recommending the construction of certain works for the improvement of Harwich,—that a harbour of refuge be formed at Dover in preference to one in the Downs or at Dungeness; and one at Seaford, near Beachy Head, rather than at Eastbourne. The improvements at Harwich have been carried out; the harbour at Dover is now being constructed; while the decision of the Commission is recorded in favour of Seaford. These facts would appear to indicate that the writer's opinion was considered sound.

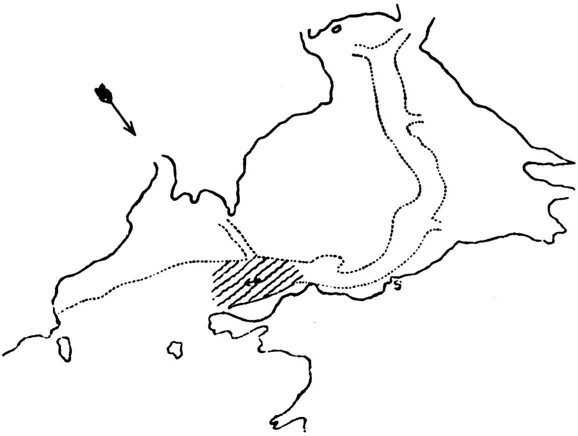
question arises as to the moving power. It could not have been the current, for that runs parallel to the main, and not towards it. The feature therefore seems fairly referable to an action imparted by the surface waves moving the pebbles in the direction of their greatest force.

Again.—In a letter to the writer from a Commander, Royal Navy, an officer of considerable intelligence, the following circumstance is alluded to: he says, "In 1838, while lying in one of H.M. ships in the port of Santander, on the north coast of Spain, we observed, upon looking over the side at high water, and when the water was unusually clear, that the bottom, composed of sand, was covered by ridges running parallel to the waves that had been on the surface during a strong breeze of two or three days' duration, but which had then been succeeded by a calm. Our anchorage was within the harbour, and the wind off-shore. The impression it made on my mind at the time was, that as the ridges lay at right angles to the direction in which the wind had been blowing, they were occasioned by a motion given to the water at that depth by the waves at the surface. The enclosed sketch will explain the circumstances more fully. You will see that the depth of our anchorage at high water (the time alluded to) was 40 feet. I do not think that the height of the waves from the crest to the lowest part of the hollow could have been more than 5 feet, as the wind was an off-shore one upon that coast. The ridges were small, apparently not more than a foot in width, and so not corresponding in magnitude with the waves on the surface, but only with their direction." The following sketch (fig. 25) is the one referred to; where the anchor represents the place of the ship, the arrow the direction of the wind,—s, the town of Santander, and the wavy lines the ridges running obliquely across the channel.

To what were the ridges owing? Not to the current, or their direction would have been across the entrance, and not obliquely to it. The surface wave was evidently the agent, and the example is useful in supplying an instance of the effect of the undulation being felt at a depth corresponding to eight times its own size, measured from crest to hollow.

The late Commander Thomas, a celebrated Naval Surveyor,

Fig. 25.



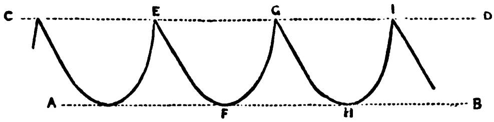
remarked, that "all rocks at the Shetland Islands at a depth of less than 8 fathoms had broken water over them during the terrific gale in the latter part of August, 1833;" and Captain Mudge, with reference to the west coast of Ireland,—"In calms we find the swell quite as heavy, and sometimes more so than in blowing weather. The swell will break in 9 or 10 fathoms, and almost always in 4 to 6 fathoms." In these cases we observe the bottom producing an effect upon the surface from a depth of 8 or 9 fathoms, and it follows, *è contra*, that the surface wave would have an effect upon the bottom at a like depth. In fact, taking into consideration the properties of water, we shall not greatly err in assuming that the distance to which such influence extends increases with the size of the wave, while it is at the same time difficult to specify its limit.

What is the nature of the power exerted in these several examples? The regularity of the ridges, for instance, forbids the idea that they arose from any confused or tumbling motion imparted by the wave to the whole mass of water from surface to bottom. The force exerted was evidently *direct*, but whether sustained or intermittent, like the wave itself, must rest upon individual opinion. The writer inclines, as will be supposed, to the latter view. If it be asked, how we can reconcile the fact of the wave being an undulation only, and yet exerting a propelling power at the same time; we answer, we cannot, any more than we can explain, in strict accordance with any physical law, the subsidence of the water in the canal which precedes the advance of the track-boat, or the descent by the stern of a vessel passing swiftly through shallow water; there are many subtle operations of Nature, and this appears to be one of them. If the fact be as stated, and we are right as to the cause, belief is not to be withheld because we cannot explain it.

There is nothing in this view inconsistent with the fact that the sea gains upon the land in most places. It may be urged at first sight, that if the effect of the wave is to heap up detritus on the shores, then the latter ought as a consequence to present a belt of flat land in front of them, not only in the embayed portions, but throughout their whole extent. Not so: the effect of waves of magnitude seems to be as stated, yet, under the circumstances of comparatively still weather, the general movement of matter (shingle excepted) must be just the reverse. Allowing, for example, that the ordinary parallel coast current is sufficiently strong to set a particle of sand in motion, then the direction of such a particle will *be outwards*, on account of the declination of the bed of the sea, and thus allow of an aggregate gain in favour of the latter. Nor is this view opposed to the fact so frequently noticed, that the cargoes of vessels foundering upon the eastern coast seldom or ever find their way to the shore abreast. The reason of this is clear: the surface wave, by keeping the vessel in motion, or making her wallow as it were, produces a burying process; the sand beneath the vessel's bottom is gradually displaced; she descends by stages, till eventually she sinks below the surface, and 'sands up' permanently.

Our remarks hitherto (intended to invite inquiry) have been confined to the effect of the wave in deep water; as to what the effect is nearer the shore, and its bearing upon the formation of a bar, we are happily not left to conjecture. The depth at which waves break in an on-shore gale may be assumed as 4 or 5 fathoms. Here the character of the wave is altogether altered, and from being an undulation, it acquires a progressive and accelerated motion. The action of the bottom of the wave being (as we have supposed) inversely as the depth, and apparently applying a power akin to that of friction, the crest of the wave is impelled forward at a greater rate than the foot of it; the summit arrives at an overhanging position, from whence it naturally precipitates itself by the force of gravity, and by the impetus it has acquired in its descent, pushes forward the mass of water directly before it. Mr. Scott Russell mentions, that, as a general rule, "a wave breaks when its height above the antecedent hollow is equal to the depth of water." However this may be, of one thing we are certain, that the effect of the downward stroke is to charge the wave with the material composing the bottom, and even to hold the heavier particles in momentary mechanical suspension, and by carrying the whole forward in a degree proportioned to its volume and rate, thereby greatly increases the effect already alluded to as existing in deep water.

Fig. 26.

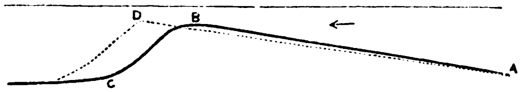


A somewhat similar operation results from the *oblique* action of the wave. If it be in front of a river where a break occurs in the continuity of the coast-line, then the successive strokes are followed by the movement of a *stream of particles* in a direction obliquely across the entrance, and it is easy to conceive that the frontage of such a river (the bar inclusive) may by this means receive a material addition in a single tide. The same wave upon the shore produces a different action altogether, owing to the return of the wave down the incline, or to the *drawback* or *undertow*, as it is indifferently termed. A stroke occurring at E, fig. 26, which represents a portion of a shore, with A B and C D, the upper and lower limits of the wave, sets a particle in motion, and carries it upward to F at the top of the incline; the succeeding drawback returns it to G, not exactly in the line of least resistance, but in a direction determined by the previous impulse of the wave. The next stroke lifts the particle from G to H; the following drawback removes it to I, and so on in continuation. This beautiful operation may be frequently witnessed on any sea-beach, and it is no unusual thing for even heavy materials to be moved in this way coastwise, several miles in the course of a day.

The fact of this constant transportation of matter in a direction before the heaviest sea-stroke, is sufficiently evident from the mass occupying the head of every indent of magnitude, an accumulation which represents the aggregate result. The mouth of the Thames, which is at the head of the North Sea, and the body of Lynn Deeps, are examples of this sort. The feature cannot be due to current action, for as every ebb is greater than the preceding flood by the amount of the surrounding drainage, the effect of the difference, aided by the declination of the primal bottom, would naturally be to prevent the deposit. Nor does the feature proceed from the excessive disintegration thereabouts, neither from the materials discharged by the abutting rivers, but only from the operation to which we have assigned it. The general fact is sufficient to show how hopeless it is to project piers or other works with the idea of getting beyond the region of moveable matter. The collection of soil about such projections is merely a matter of time, and when they ultimately advance the coast-line by their own extent, the process is continued exactly as before.

To apply the foregoing particulars to the case of bars. We have seen that the action of waves, whether direct or oblique, is to move the detrital matter in the bed of the sea in the direction before their heaviest stroke (on our eastern coast from N. to S.). One proof of this progression is afforded by the beaches fronting the sheltered or recessed portions of the coast-line, and as the action of the wave must needs be continuous, the only sound and legitimate inference seems to be, that a similar feature would exist across the entrance of a river, were it not prevented by the usual flow and reflow. *The evidence of such a struggle is the bar itself*, which may therefore not improperly be considered as the balance of power between two forces; that of the sea to heap up material and close up the river on the one hand, and the reflow of the tide with the land waters to scour the impediment away, and keep the river open on the other. If we are correct in this position, the fact would become more apparent in the increase or decrease of the bar, upon the preponderance of one power over the other, and this is just the case. Select any of our bar harbours on the eastern coast for example: a succession of land floods deepens the bar several feet, while easterly or on-shore gales will bank it up to a like amount. In truth, the history of each presents a series of fluctuations, which may be traced to the foregoing circumstances as the cause.

Fig. 27.



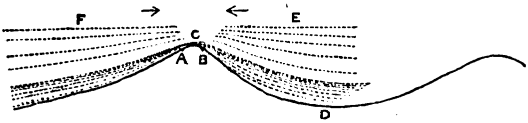
So far as to the origin of bars and the changes to which they are occasionably liable from the alternate preponderance of the powers within or without. There is also no doubt a daily variation from the action of every flood and succeeding ebb. Thus in figure 27, representing a section of a bar in the sailing channel, we can readily imagine that the effect of the flood, while it lasts, is to move or roll the particles from outside up the incline A B, which is the sea-face of the bar, and then to precipitate them down the steeper incline B C, which is the river-face; and thus during a single flood there may be a small but positive movement of the crest of the bar from B to D, but this addition to the inner face will be again removed by the reversed action on the return of the ebb. The ebb, being stronger than the flood, from conveying the land waters in addition to the tidal quantity, ought to increase the depth over the bar to a degree proportioned to such difference of strength; and this it would do, were it not that the flood has the wave-stroke to assist it in disturbing the particles, and thus regulates the height of the obstruction, according to the balance thus established; in other words, maintains it at that level which is the result of all the actions. The effect of the occasional preponderance we have noticed upon the height of the bar *leads us at once to the true direction of improvement*, for if means can be devised to *establish* the inner power as the superior one, then the outer disturbing causes would be held in check; the bar would be lowered, and the sailing channel over it improved in the same proportion.

We have now to show that the explanation we have given of the cause of bars is not incompatible with their non-existence at the mouths of some tidal rivers, as the Thames, Severn, Humber, Forth, and Shannon, &c. The reason of the latter phenomenon is the configuration of the shore, or it arises from the manner in which the river disembogues with respect to the coast on either side of it. Generally speaking, whenever a river opens out at the head of a bight of any extent, as in the above cases, there can be no bar; the direct action of the wave exists as upon a plain coast, *but it is in deep water, and spread over a great extent.* As it advances upwards between the converging shores, and is acted upon by the depth, it gradually decreases in size; and before its arrival at a more contracted portion of the estuary, and where under other circumstances would be the bar, the wave is altogether destroyed, *and the current becomes the sole agent of change.* Take the approach to the Thames as an example: allow a line drawn from the North Foreland to Harwich Naze, to represent the outer entrance of the river, and also the crest of the wave propelled before an E. N. E. gale. There will be no weight of sea after the sands are once entered, for although these latter are disposed in a direction corresponding with, instead of across the track of the undulation, they will aid in reducing the wave, till, at the Nore, the proper position of a bar, the wave is altogether destroyed, and the belly or alveus of the Thames is found to be perfectly uniform, presenting no tendency towards any step or obstruction.

The oblique action of the wave is also harmless. *It is confined to the shores on either side, and its force is spent along them,* till, on its arrival at a more sheltered position, it is also in turn dispersed. The same reasoning applies to the other examples above cited; to the rivers at the head of the Wash, and to any whose outlets are similarly constituted. Arguing from analogy, therefore, and for the reasons we have stated, there can be no bars at the mouths of rivers opening out at the head of deep bights, while, on the contrary, they will assume their worst form in the case of those streams which debouch at right angles upon a plain coast.

A bar also cannot form at the narrow entrance or gorge of an extensive basin, such as that at Cromarty Firth, Cork Harbour, Milford Haven, and such like. No doubt the action of the sea is felt at the bottom, but it does not result in a heaping up process. In short, wherever as in these cases the water is too deep to allow of the wave being charged by the downward stroke with the soil composing the bottom, there can be no bar, and the case is in exact contradistinction to a harbour with a gradually shelving frontage, on which a bursting sea will generate, and then in turn will *heap one up*.

Fig. 28.



Again.—A river having its entrance in a small bay or bight does not reap any of the advantages conferred by this feature when in an enlarged form; and we must not by any hasty generalization confound the two cases, for the difference is practically very important. The minor indentation is a disadvantage, and for this reason: in the margin of the sea, and in exact contrast to those of a river, *points are steep and bights are shallow*, a feature resulting from the action of the coast-tide. Thus in figure 28, allowing the dotted lines F and E to represent the converging lines of the flood and ebb streams upon the point C, then a river opening out at A will have its entrance swept and its bar *kept short* by the concentrated action of the flood, while, with a river discharging at B, a similar effect would be produced by the ebb. If, however, we remove the entrance to D, the head of a shallow bight, where the tide is deflected and weakened, and more soil is enabled to lodge itself in its migration round the coast, then there will be a *greater breadth* of obstruction, and consequently a worse bar for the outset to overcome. This leads us to the fact, illustrated by many practical examples, but which it is needless here to particularize, that the more the embouchure of a river is made by artificial works to assume the form of a point with respect to the coast on either side of it, the shorter will be the bar, and the more the latter will be within the influence of the scourer, while, on the contrary, the recessing process will produce the opposite effects.*

Again.—It sometimes happens that a river of small natural power opens out upon a plain unprotected coast, with a fringe of soil (shingle perhaps) in constant movement, but which the trifling amount of its back-water prevents it from overcoming. The Proteus-like nature of the bar in front assumes a different form with every wind, and there is no calculating one day what may be its shape on the following. A harbour thus beset with natural difficulties is afflicted with a chronic disease, which the most judiciously projected works can barely modify; a state of things to be deplored truly, but it cannot well be remedied.†

Reverting for a moment to what we have assigned as the origin of a bar. If it be true that it is really the balance of power between two forces, the fact has an important bearing upon what has been so much insisted on in previous chapters, viz., *the strict preservation of the tidal quantity.* It is evident that the agent for keeping a bar down must not only be powerful, but *constantly operative.* If the capacity of the river as a tidal receiver be sacrificed, and the outlet be made dependent on land floods for keeping it open, what follows? These agents in our climate are confined to a particular season, and during the greater part of the year they are almost dormant. As it is

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* In 1847 the description of the character of Sunderland Bar, by the late resident Engineer, was as follows: "Depth 4 feet at low water—but a short distance from the pier-heads—narrow and shelving, with deep water on either side." In 1850 the writer had to report upon the effects of certain works south of the harbour; his opinion was as follows: "That when the works were fully carried out,—the pier-heads thereby placed in a bight instead of upon a point as formerly, and the coast-tide deflected away from the harbour, sand would lodge in considerable quantities in and about the entrance, and widen the bar." In 1852, owing to the above cause, aided by other circumstances, the state of the bar as to height and position caused serious alarm among those interested in the trade of the port. It is now kept in partial subjection by dredging, but it is generally felt that an extension of the piers will eventually be necessary to meet the altered condition of the entrance.

† In 1844 the writer submitted to the Commissioners of Southwold Harbour a plan for its improvement. In the evidence of Lieut. Ellis, R. N., the talented Surveyor in charge of the port, before the Tidal Harbours' Commission, he thus alludes to it: "Upon general principles it is the best that has been propounded."

no unusual occurrence for a single gale to bank up a bar several feet, a succession of strong winds at the beginning of the dry season would raise it above water, *and in this helpless state it would remain till the floods of winter forced a channel through it on their passage to the sea, and which would be again blocked up upon their cessation.*

Before concluding this branch of the subject and offering a summary, we notice one of the other theories which account for the formation of the feature, but only one, viz., "that it results from the outgoing current becoming inert at its junction with the waters of the sea, and there depositing the matter held in suspension." An objection fatal to this theory presents itself in the simple fact, that such junction takes place at a position *considerably beyond that usually occupied by bars*, and instead of a stagnation occurring, the outward stream becomes *gradually merged* with the coast-tide, both in its direction and rate. That a river origin cannot be assigned for a bar is clear, for though more material is suspended during land floods than at other times, yet their effect, as we have seen, is to depress the bar, and not to raise it. It is very possible that a portion of the matter so rejected from the river and dropped outside, may, on the occurrence of the wave, be forced in upon the bar, and in this indirect way add to its height; but we may safely affirm that the mass of soil, including the bar, fronting any of the entrances on the eastern sea-board, is derived, not from the river within it, but from the direction of the heaviest wave-stroke, viz., the rivers and shores north of it.

Lastly.—Upon a careful consideration of all the circumstances touched upon in this sketch of first principles, the depth over bars, or their degree of excellence, will be found to assume nearly the following order, varying in short with the exact measure in which they fulfil one or other of the foregoing conditions.

1. Rivers discharging themselves at the head of deep bights, such as the Thames, Shannon, Severn, and Forth.
2. Rivers upon a plain coast, but recessed from the sea ebb, as the Esk at Montrose, the Dee at Aberdeen, &c.
3. Rivers upon a plain coast, but recessed from the sea flood, as the Tyne, &c.

4. Rivers upon a plain coast, as the Wear, Deben, Ore, and Blyth, &c.

This leads us to the subject of piers, on which we can offer but one or two remarks, and they must be general rather than particular. Piers have often been projected, and every good effect expected to ensue, *simply because they were piers,* without considering the necessity for strictly adapting the means to the end, and examples are not wanting where they have been followed by results the reverse of those predicted. When such works are undertaken, the object proposed ought to be well considered, and things inconsistent in themselves should not be pursued at one and the same time.* No pier or piers can be proposed as an universal panacea, for unlike the improvement of the bed of a tidal river, where one system is applicable and nearly in the same degree in all cases, each outlet must be treated *per se,* as they have sufficient variety both in the obstructions to be overcome, and the natural power for accomplishing it, to constitute each a distinct example. The following precautionary remarks, however, naturally suggest themselves.

Piers are only to be projected for one of two reasons, or for both, as the case may be, *either to afford internal protection, or to prevent a wastage of power.*

It is useless to project piers at the mouth of a tidal river with a view of getting beyond the bar; *wherever the outer ends of such works are placed, the bar will still be found in front of them.* The intention therefore can only arise from the want of a due regard to the cause of the existence of the feature.

Piers are not to be protruded like *stop-waters* across the coast current as a means of adding to the tidal quantity. We have already stated, under the head of 'Theories,' that the reason of the tide entering a river is owing to the demand of the latter

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* In 1845 the writer was applied to for an opinion upon a projected southern outlet to Sunderland South Dock, and a material departure from the original conception was recommended. The outlet is now being constructed in the position, and nearly of the form, indicated by the writer.

as a receiver upon the source of supply, or, in other words, because the level of the river is below that of the sea: *therefore, unless piers increase this difference, they do nothing towards increasing the quantity admitted.* That they cannot do this is palpable, for the effect to be produced by the projection of any possible pier in the way of causing the passing tide to 'heap up' against it, would in practice amount to nothing. For example: if the abrupt protrusion of the sea margin of the North Riding of Yorkshire beyond the general line of the coast north of it, only causes the high-water level to *gorge up* eight inches, what effect is to be produced by the length of a pier, more especially as in nine cases out of ten a similar action upon it is prevented by out-flanking points? It is true that the depression of the bar by decreasing friction is in the direction of tidal increase, but this depression itself results from the effect of the piers upon the scourage, and not from their interception of the coast-going set.

Piers, strictly speaking, have no necessary connection with any river system; that is, while they insure the proper direction of the natural power possessed by the river, they do nothing towards its maintenance; *they confine and direct the current, but it depends upon the system of treatment pursued within as to what amount of current is to be thus directed.* To make our meaning more clear: The sea affords a standard rate of rise and fall which is not affected by interior works. It regulates the time of the passage of the tidal water due to the river in and out over the bar; therefore the greater the amount to be passed in the interval between high and low water, the stronger the current; and the less the quantity, the weaker the current and the scourage also. If a smaller quantity by the agency of certain works is made to scour the interior channel of the river fathoms deep, still this is purely a river question, and does not benefit the bar. Neither the bar nor the piers can profit by the well-regulated energy of the *smaller quantity* after it passes, and before it returns to them again. *The question, as it affects the piers and the bar, is confined to this: not into what form of receiver the tidal water enters, but into how large an one.*

Though, as we have said, each example of a river outlet must be treated upon its own merits, yet, in the application of piers for improvement, it will be found, in the majority of cases, that the first step is to accept the natural position of the bar, and then to secure the preponderance of the inner power as the most effectual means for keeping the obstruction at the lowest possible level. *This is the great end to achieve by the erection of piers*, but into the question it is beside our present purpose to enter.

Having now dwelt at some length upon the origin of bars, *and more especially upon the intimate relation which subsists between their height and the tidal quantity passing over them*,—having also shown the dependence which must be placed upon the latter both as a means of preservation and improvement, and offered a few ideas upon the principal points to be kept in view in the projection of piers, we must here pause. It might have been useful to have unfolded what we conceive to be their proper application in three selected instances of coast outline,—examples so widely different in character, that they may be said to embrace all the varieties; but the subject is manifestly too extensive for the present work, which is confined to the question of the improvement of the channel of a river rather than of its outlet, and to the elucidation of principles rather than of details. On a future occasion, if time permit, Piers, and the points of interest connected with them, will be made the subject of a Supplementary Treatise.

The writer has now finished the task he assigned himself. It has been shown, that although the operations of Nature may be somewhat indistinct in tidal rivers, still, to those who go to the study with an unbiassed judgment, enough of certainty is apparent on which to base a true system of river improvement; and that such a system has for a primary doctrine,—that tidal quantity determines sectional capacity nearly throughout the tidal development;—that a decrease of one is surely followed by a decrease of the other, *and that this relation is not only coincident but derivative;*—next, that several leading theories are highly objectionable, inasmuch as they are opposed to common observation;—and lastly, that river operators of the present day are divisible into two sections, and their systems may thus be classed. One is natural, for it is regulated by a judicious attention to the form in which the river has been received from the hands of Nature; the other unnatural, as it involves a radical change in its entire features. One in its character is ductile, concentrating the power of the stream, but allowing its superficial range; the other inflexible, confining it within a space it was never intended to occupy. One is a conservating process, insuring the greatest improvement in the navigable condition of the river, without any sacrifice of power; the other is destructive, being the promotion of depth in the interior channel at the expense of the outlet, *and consequently of life itself.*

The conclusion must be a simple warning.

The subject is of local importance. Several of the principal ports, such as Liverpool, Hull, Newcastle, Yarmouth, Montrose, and others, possess, in the wide expanses above them, storehouses of natural power on which their very existence as ports depends, but which, under one pretext or another, will continue to be the common aim of the land-gainer or the experimentalist. LET THEM LOOK TO IT.

The subject is of national importance, but more especially at the present time, when the want of available harbours is increasingly felt, and when the extended use of steam navigation has given a commercial and political value to every sheltered creek. God, for the furtherance of his own wise designs, seems to have marked out this country by her isolated position and other advantages for pre-eminence in the scale of nations; but instead of preserving with the most jealous care the means upon which such supremacy must be dependent, we are charge-able with the folly of allowing them to slip away by degrees; slowly it may be, but not the less surely. The general fact of harbour decay has been brought before the country by men of the first eminence, and that venerable and patriotic senator, Mr. Hume, has also called attention to the subject; *but though the cause is closely allied with that of humanity*, the most marked apathy upon the subject continues to exist, and at the present moment we are affording the curious spectacle of a commercial people, to whom the means of inter-communication are of inestimable value, *but who nevertheless bestow less grave legislative attention upon the whole question than upon the smallest matter of parish polity!*

Harbour deterioration proceeds from three principal causes, which we do not here specify. Mr. Rendel's candid opinion upon one point, however, cannot be too frequently borne in mind. "I believe," he says, "more harbours have been injured by injudicious applications of what were considered improvements than by natural decay." It does appear singular, that at a period when the most rapid strides are being made in practical science, river amelioration should prove the solitary exception. In no part of the practice of Engineering is it so necessary that the *terminus à quo* and the *terminus ad quem* should be clearly understood, as in the projection of river and sea works; and yet in how few instances can we, *after balancing all the results*, point to a work of the sort, and say it has been really successful! Hydraulics, in short, may be called a new study, and the state of existing knowledge respecting it is very fragmentary and unsatisfactory. Far better would it be for the interests of the country to suspend all operations at once, and enter upon a series of national experiments, than pay the costly price we are now doing.

In making these remarks, the writer must not be understood as wishing to detract one iota from the well-merited fame of Engineers of the present day, for we owe much to them, and, in one sense, they are the men of the age, and equal to its exigencies. Marine projection, however, appears to be their weak point, and no one will admit it more readily than Engineers themselves.

Lastly. An intelligent foreigner, while alluding to the failures which generally precede the adoption of any social or other improvement in this country, remarked, "The English never count their dead in the battle of progress." If we are wise, an exception will be made in favour of the subject discussed, for, in the majority of cases, a loss, when once incurred, is irremediable. Our failures in river-improving and harbour-making have been numerous; but hitherto they have conveyed no lesson of the slightest practical benefit. This dear-bought experience, however, will not have been in vain, if now, *at the sixth hour,* it is improved to the establishment of a correct principle—a solution as desirable as the writer believes it to be possible, for it would conduce to the advancement of the material interest of the country, and be also more in harmony with our character as a practical people.

THE END.

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