XXIII. *Observations on the Junction of the Fresh Water of Rivers with the Salt Water of the Sea.* *By the Reverend* JOHN FLEMING, D. D. F. R. S. EDIN.

(Read June 17. 1816.*)*

IT is possible, that the following observations may contain little that is new to those who are familiarly acquainted with the details of the science of Hydrostatics. But as I have not met with any remarks on the subject, in the course of my limited reading, the experiments which were performed, and the conclusions to which they lead, are here submitted to the consideration of the Royal Society.

When the flux of the tide obstructs the motion of a river, the wave has been supposed to produce its effects in the same manner as a dam built across a stream. This popular opinion, however, appears to have been adopted without sufficient consideration, as it can only hold true, in those cases, where the opposing fluids are of equal density, but never at the junction of opposite currents of fresh and salt water, which are of different densities. In this last case, where currents of fresh and salt water come in opposition, the lighter fluid, or the fresh water, will be raised upon the surface of the denser fluid, or

the salt water, and when the stronger current of the tide has reversed the direction of the stream, the salt water will be found occupying the bottom of the channel, while the fresh water will be suspended or diffused on the surface. This view of the matter occurred to me in 1811; but it was not until the 29th of September 1813, that I had an opportunity of verifying the conjecture, by an examination of the waters of the Frith of Tay.

Flisk Beach, opposite to which the experiments were made, is situated a considerable way up the Frith, being upwards of sixteen miles from Abertay and Buttonness, where the Frith of Tay actually joins the German Ocean. The channel of the Frith at this place is about two miles in breadth; but upwards of a mile and a half of this extent consists of sand-banks, left dry at every ebb of the tide, and during flood, covered with from three to ten feet of water. These banks are separated from one another by deep pools, or *lakes* as they are termed, which occasion great irregularities in the motion of the currents. The channel of the *river* is near the south side. It is about half-a-mile in breadth, having in the deepest part about eighteen feet of water, when the tide has ebbed, and upwards of thirty feet during flood.

The apparatus which I employed was very simple: It consisted of a common bottle, with a narrow neck, having a weight attached to it. Besides the cord by which the bottle was lowered, there was another connected with the cork, in such a manner, that I could pull it out when the bottle had sunk to the place of its destination. The weather was favourable, and, on the day of the experiment, there was no wind to disturb the surface of the stream.

With this apparatus, I proceeded to the middle of the channel of the river, at *low water*, when the current downwards had ceased

ceased to be perceptible in the boat at anchor; and I obtained water from the bottom, the middle, and the surface of the stream. The water taken from the surface of the stream was fresh, and tasted like ordinary river water. The water taken from the middle, was not perceptibly different; but that which was brought from the bottom was sensibly brackish. The water from the surface did not contain any salt, as a thousand grains of it, when evaporated with care on a sand-bath, left only a grain and a half of residue, apparently mud, which, when applied to the tongue, communicated no impression of saltness. The water from the middle of the stream yielded two grains of residue, when the same quantity was evaporated, of a whiter colour than the former, and having a perceptibly salt taste. The water from the bottom, which was saltish even to the taste, yielded four grains of saline matter. According to these experiments, the layers of water were arranged according to their densities, the heaviest water occupying the bottom of the stream, and the lightest floating on the surface.

At *half-flood*, I repeated the experiments on the waters obtained from the same situations as before. The water at the surface had now become very sensibly salt to the taste, and thus gave decided proofs of the progress of the tide. The three bottles of water now obtained, yielded results, not in unison with those already taken notice of. The arrangement of the different strata of water, according to their densities, as observed at ebb-tide, was in some degree reversed; for here the water at the surface was salter than that which was obtained from the bottom, and the water from the middle was salter than either. A thousand grains of water from the bottom, yielded by evaporation only ten grains of saline matter, while the water from the surface yielded eleven grains, and from the middle twelve grains, by the same process.

This anomaly is easily accounted for. Were the current of the tide confined entirely to the channel of the *river*, an arrangement of the waters, similar to that which existed in the first experiments, would have prevailed. But during the flowing of the tide, the sea-water soon occupies more than the channel of the river, and spreads itself in various streams among the hollows of the sand-banks. These streams reunite at different places with the principal current, and, in this manner, prevent the salt and fresh waters from gaining their natural relative position. But as soon as these sand-banks are covered with water, the tide proceeds with regularity in its course, so that the different layers of water can then arrange themselves according to their specific gravities.

A thousand grains of water obtained from the bottom, at the *height of flood*, yielded by evaporation twenty-three grains of salt, while the same quantity of water from the middle yielded only eighteen grains; and from the surface only seventeen grains. This was a difference of no less than six grains, and seemed to afford a decisive result.

In order, however, to complete the series of observations, I examined the conditions of the currents at *half-ebb*. The same irregularities prevailed, as before observed at half-flood. A thousand grains of the water, from the bottom, yielded after evaporation eleven grains of salt; from the middle, nine grains, and from the surface, twelve grains. At this time the densest water was at the surface, and the lightest occupied the middle. The cause of this was obvious. Extensive portions of the sand-banks had already been left dry by the receding tide, and various currents of water, disjoined from the main stream by the inequalities of these banks, were now re-uniting with it, through various channels, and disturbing the natural arrangement which had prevailed during the time of flood.

Although

Although the Frith of Tay is very ill calculated for experiments of this kind, from the circumstances already taken notice of, still the premises which we have stated seem to warrant the conclusion, that when the wave of the tide obstructs the motion of a river, and causes it either to become stationary, or to move backwards, the effect is produced by the salt water presenting to the current of the river an inclined plane, the apex of which separates the layer of fresh water from the bed of the channel, and suspends it buoyant on the surface *.

It may here be observed, that this inferior current of salt-water, will never reach that point of the bed of the river, which is intersected by a line drawn perpendicular to the altitude of the wave of the tide, in the ocean, at the mouth of the river. This point is undoubtedly the place at which the salt-water would arrive, at every flood, were there no fresh-water current, as has been demonstrated with regard to the waters of the Tay, by the accurate observations of Mr JAMES JARDINE. But as the motion of the current of salt-water is retarded by the opposite current of the fresh-water, and the apex of the wedge which it forms, also washed away by the same agent, the point which the salt-water reaches will be considerably lower than the summit of the tide-wave with which it is connected.

The surface of the higher part of the river, whose elevations and depressions are influenced by the movements of the tide, will necessarily attain a higher level than the summit of the tide-wave, in consequence of the lower specific gravity of the river-water, when compared with the denser column of sea-water,

* I understand that my friend Mr ROBERT STEVENSON has made similar observations at the mouth of the Dee, near Aberdeen, and also on the Thames, and that his conclusions and my own nearly coincide.

which it counterbalances; and this, independent of the progressive motion of the tide in the river.

If the view which we have taken of this subject, in reference to the progress of the salt water, be considered as just, it will enable us to explain some of the phenomena of nature, at present rather perplexing, and may even be useful in its practical application.

In examining the vegetable productions of the banks of rivers, at their junction with the sea, we are sometimes surprised to witness the growth of plants, considered as the natural inhabitants of the sea-shore. But our surprise will cease when we reflect, that the sea-water proceeds farther up the river at every flood-tide than the sensible qualities of the water at the surface indicate; so that the plants, which we hastily conclude to be out of the reach of the salt-water, are still within the sphere of its influence. Thus, at the Beach of Flisk, and even farther up the river, the *Fucus vesiculosus* (the species commonly cut for making kelp) not only vegetates, but in its season appears in fructification.

But that which proves in a still more decisive manner, the action of the inferior stratum of salt-water at the place, is the growth of the coralline termed *Tubularia ramosa* (Ellis's Corallines, Tab. xv. fig. A.), and another of a different genus, closely resembling the *Sertularia gelatinosa* of Pallas. There are likewise some traces of *Flustræ*.

A knowledge of the facts which we have already stated, may be of use to those who are engaged in the erection of salt-works at the mouths of rivers. In such situations, the openings of the pipes for obtaining the salt water, should be placed as near the bottom, or as deep in the water as possible; and water ought only to be drawn during the height of flood-tide, when the fresh-water is diffused over the surface.

Even

Even to navigators, an acquaintance with this subject may sometimes be of use. Thus, for example, when entering a creek in an unknown coast, they may easily ascertain whether any streams of fresh water flow into it, by examining the comparative density of the water taken from the surface and from below.

These experiments appear to give countenance to the opinion which supposes that the water at the surface of the sea contains less salt than the water at the bottom. This may be expected to take place in the neighbourhood of continents, at least, whatever may be the case in the open ocean. During winter, the difference is probably very considerable, as at that season the rivers incessantly pour vast quantities of fresh water into this great reservoir, while but a small portion is abstracted by evaporation. In the Frith of Forth, the difference between the dense water of summer and the diluted water of the winter season, is as eighteen to sixteen, and that even as far down as Prestonpans.

MANSE OF FLISK,
11*th March* 1816.

XXIV.