

XXIII.—*Notice respecting the Depletion or Drying up of the Rivers Teviot, Nith, and Clyde, on the 27th November 1838. By DAVID MILNE, Esq., F. R. S. E., F. G. S.*

Read March 18. 1839.

THE Teviot, Clyde, and Nith, are well known to be among the largest rivers in the south of Scotland. In the lower parts of their course they are navigable; and all along their banks, nearly up to their sources, there are innumerable mills and manufactories, dependent on the continuous flow of their waters.

On the morning of the 27th November 1838, the channels of these rivers were, in the upper and middle parts of their course, found almost entirely empty. The thousands of water wheels, many of which had for years, without interruption, been turned by their currents, suddenly stopped. Immense quantities of fish, inhabitants of their deep and rapid streams, were destroyed by being left dry, or being caught with the hand in deserted pools; and in places where it was usually difficult for even horses to ford, it was easy for children to walk across without wetting their feet.

The phenomenon of a large river thus disappearing entirely from its channel, for many miles, was one in its own nature well calculated to excite interest. But being accompanied by the striking circumstances above mentioned, it could not fail to excite astonishment among all living on its banks, and no small degree of alarm among those who, in various ways, depended on these rivers for daily occupation and support. The subject became naturally one of general interest, and occasioned much speculation and inquiry. The interest so excited was greatly increased, on its being discovered that the phenomenon had happened not merely in one large river, but in several; and that, though these rivers were far distant from each other, the phenomenon had occurred in all, on the same day, and even about the same time of that day.

On making local inquiries, it was ascertained that the phenomenon was not without precedent. In the Scots Magazine, and other periodical repertories of remarkable occurrences, accounts were found of the disappearance of several rivers from their channels, at different periods, within the last century. These periodicals contain long and frequently renewed discussions as to the cause of the phenomenon, which show how much the public attention was interested by it, and

how little the various observers, or even scientific men, were agreed as to the true explanation.

When the phenomenon was repeated last November, though on a scale much more striking than on any former occasion, the same speculations were excited, and the same diversity of opinion prevailed, as had previously existed. It is of course unnecessary to advert to all the theories which were started, but the most plausible of them may be noticed.

Some persons conceived, that the strong south-easterly wind which blew during the night of the 26th and following morning, was of itself sufficient to produce the effect. It was observed that the Teviot and the Nith flowed, for the greater part of their courses, in an easterly direction, and that the Clyde, in the higher part of its course, likewise flowed in this direction; so that the easterly gale blew up against these streams, and might have obstructed, if not stopped in some places, the flowing of their currents, and thus have cut off the usual supply of water from the lower parts of the river.

Others thought, that the frost which prevailed during the night of the 26th, and morning of the 27th, must have frozen up the springs and rivulets at the sources of the rivers; or that it, at all events, stopped the flowing of the current in those parts where there were caulds or damheads,—by forming a barrier of ice along the top of them.

Others, again, imagined, that the phenomenon might have been caused by an earthquake, or rather by the widening of the natural fissures and rents abounding in strata, which is known to take place during an earthquake. This opinion was suggested by the fact, that, in Italy, the temporary disappearance of rivulets, even of considerable size, is not an unfrequent occurrence before or during an eruption. Professor Phillips, in his article on Geology, published in the last edition of the *Encyclopædia Britannica*, mentions as the effect of volcanic agency in England, that, “in (the year) 1110, the Trent was dry at Nottingham for a whole day; and that, in 1158, the Thames was dry at London.”—(P. 245–6.) A similar phenomenon was stated to have occurred in Scotland on the 6th January 1787, on which day the shock of an earthquake was violently felt in the parishes of Strathblane and Campsie, and a large district of country in the west of Scotland. On the same day, it appears that the Woodhead burn, which runs through the parish of Strathblane, and there turns a mill, left its channel dry for a short interval; and, what is still more remarkable, there was likewise on that day a stoppage and desiccation of the Clyde.

In farther explanation of this last theory, I may here allude to what is familiar to all geologists, that, in secondary rock districts, and especially those occupied by carboniferous strata, there is hardly an acre which is not intersected by numerous cracks or fissures, reaching from the surface to an unfathomable depth, and varying in width from a few inches to many feet. There

is one of these fissures (near Musselburgh) which exceeds fifty feet in width; and throughout the Lothian coal-field, there are many hundreds of them exceeding six feet in width. Now the partial elevation of the earth's crust by subterranean action, in whatever way it takes place, must widen these natural fissures, so as to permit water to escape by them. A Fellow of this Society mentioned to me, that, in 1834, near Liverpool, when the shock was felt there of the earthquake which transmitted its vibrations through the south-eastern and midland counties of England, the slines or cutters (as these fissures are called by quarrymen) were observed to open, in a stone-quarry near Liverpool, and after a short interval to close again.

Such were the most plausible of the theories adopted to explain the remarkable desiccation of the Teviot, Clyde, and Nith, on the 27th November. But I should term them *conjectures* rather than *theories*; for they were formed without any previous ascertainment of even material facts, and therefore could not be relied on, to the least extent, as affording a true explanation of the phenomenon. I therefore deemed it to be my first business, to obtain from different persons who had themselves witnessed the circumstances, or could easily ascertain them on the spot, a full and accurate statement of what had occurred.

(1.) I shall not quote at length the reports themselves, but shall give merely a summary of the material facts and circumstances contained in them.* I may only here mention the names of the gentlemen on whose information I have relied; and I do so from a conviction, that I shall thus afford a proof to all who know these gentlemen, of the truth and accuracy of their communications.

The state and appearance of the TEVIOT were described in letters from ANDREW JERDAN, Esq. of *Bonjedward*, in a letter, dated 31st December 1838, addressed to Professor FORBES.

Dr DOUGLAS Junior of *Kelso*, in a letter addressed to me, dated 21st January 1839.

Dr WILSON of *Kelso*, in two letters to me, dated 21st January 1838, and 15th March 1839.

Rev. Mr AITKEN of *Minto*, in two letters to me, dated 27th January and 7th February 1839.

The temperature of the district during the 26th and 27th November, and the state of the wind and weather generally during these two days, was obtained from meteorological registers kept by the

Rev. Mr WALLACE of *Abbey St Bathans*, near *Dunse*.

Mr JERDAN of *Bonjedward*, near *Jedburgh*.

Mr DUDGEON of *Spylam*, near *Kelso*.

* The reports themselves were read to the Society, and are in the possession of the author, who will give access to them, to any one who may desire to examine them.

I may be permitted to make two short extracts, descriptive of the phenomenon generally, in order to shew more clearly the bearing of the facts as given in the summary.

The first extract I shall give is from Dr DOUGLAS's letter.

"At the mill at Maxwellheugh (immediately above the confluence of the Teviot with the Tweed), the supply of water in the dam began to diminish at 6 A. M. Nov. 27. It nearly ceased at 8 A. M. The whole water in the river was diverted by means of the cauld into the mill-lead, but the quantity was so small that the wheel could not be kept in motion. This state of things continued until 12 noon, when the flow began to be re-established, and at 1 P. M. the river had assumed its ordinary size. The miller distinctly told me, that the supply came gradually, and not *in a rush*.

"At *Hawick*, six miles above Minto, a correspondent there writes me, that, during the morning and forenoon, the mills were stopped for want of an adequate supply of water, and that near mid-day, the supply was again established, and the mills again at work. For several miles above Hawick, the river was remarkably small, and the same appearance was observed in the tributaries; but this, he observes, is of such common occurrence during frost, that it scarcely excites attention. The bed of the *Rule Water* (which joins the Teviot just at Minto), was so dry, that a friend told me he walked through the channel without wetting his feet."

Mr JERDAN, in his letter to Professor FORBES, states that, "on the morning of the 27th, which had been freezing hard during the night, and which was an uncommon cold frosty day, with a keen and bitter wind from SE., the miller, who was at his work between five and six, on setting the mill agoing, found a great rush of water, so much so, that he could hardly check it sufficiently. On going up to the sluice or grating at the head of the dam, to his astonishment he found the cauld or weir so frozen with the bitter night and high wind blowing right on it, that not a drop was going over it, and a bank or wall of ice, about 16 inches high he thought, was formed on the lip or top of the weir, by the accumulation of the floating ice, and the severity of the frost, and which kept the whole water in the pool, and so forced an additional quantity down the dam, when the floating ice was removed from the grating, which he had to do occasionally. From this obstruction, which seems to have been very effectual, the stream immediately below the weir was in a great measure dry, so much so that he could have easily gone over it. In a few hours the accumulation of water carried away the ice from one-half of the cauld, which is separated from the other by an island, and the water flowed as usual, covering all the bed. The ice on the other part of the weir, remained most part of the day.

"This easily explains the occurrence at Maxwellheugh, where, on examination, I find the water was not only dry below the cauld, probably from the cauld

freezing in somewhat the same manner, but when the mill was set agoing, the pool above was drained in a short time to the level of the dam-head, because Mr MEIN's, which is about three miles above it, had obstructed the current in the manner described."

Dr WILSON mentions in his first letter, that, " at Roxburgh and other places, persons crossed the water dry-shod; and a boy crossing from Trows to Heiton, caught several eels which were struggling in the shallows."

Dr WILSON adds, in his second letter, that there was in the Teviot, on the morning of the stoppage, little or no ice in the stream. " The miller at Roxburgh (he says) finding the mill stopped, looked out for ice, and discovering none, and finding his dam empty, thought it was the last day! Neither he nor any other miller would have been surprised, had the stoppage been caused by ice, which is an occurrence so common, that they are generally provided with large wooden mallets, to be used for its removal. Mr DICKSON of Hawick, who was not likely to be an inattentive observer, as his large manufactory was stopped on the occasion, stated to me that there was no ice, unless a little at the edges of the pools."

These extracts are sufficient to shew generally, the nature of the phenomenon in the Teviot.

I shall now give a summary of the most important facts stated in the letters of the different gentlemen above mentioned, calculated to explain the phenomenon. It appears from these letters—

1. That there was an almost *total cessation* of current, and in many places an absolute depletion of the bed of the Teviot, in that part of its course situated betwixt Kelso and Hawick, and that the same phenomenon happened in most of the streams which joined it.

2. That, with one exception, all the mills on the river, from Kelso to Hawick inclusive, and most of the mills on the tributary streams, were stopped from want of water,—a circumstance which proves that the phenomenon arose, not from *obstructions* by ice or otherwise on the caulds or dam-heads, but from a *failure of water in the upper parts of the river*.

3. That when the current began to flow again, there was no sudden rush of waters, such as would have arisen from the mere stoppage of the current by obstructions, but that there was a *gradual restoration* of the current.

4. That the diminution and disappearance of the water took place in the upper parts of the Teviot and its tributaries, before it took place in the lower parts. (For example, it was noticed on the Rule Water at 11 P. M. on the 26th November, whilst it was not noticed in the lower parts of the Teviot till next morning).

5. That the restoration of the current took place first in the upper parts of the Teviot and its tributaries, the smallest and shallowest of the latter being the first to indicate motion.

6. That, during the night of the 26th, and morning of the 27th November,

there prevailed over the whole district drained by the Teviot and its tributaries, a keen and parching gale from the E.S.E., accompanied by a frost, which reduced the temperature of the air to 25° or 26° Fahr.

7. That ice was formed during the night of the 26th November, in the higher parts of the Teviot, and especially its tributaries,—that the small streamlets, and even some of the springs at or near the sources of the river, were frozen, and were consequently stopped,—that, in some of the larger tributaries, ice formed both on the surface and at the bottom of the water, and that in one place the whole body of the stream was congealed into a solid mass,—and that across the lip or edge of one cauld on the Teviot, a barrier of ice formed from sixteen or eighteen inches high, which there completely obstructed the flowing of the current for several hours.

8. That the rivers in which the phenomenon was most observed, have an easterly direction, and are neither deep flowing rivers, nor sheltered by high banks or woods. The Tweed and the Eden, in neither of which the phenomenon occurred, are both deep and rapid, and, besides being sheltered by high and wooded banks, have not so many tributaries as the Teviot, so that their waters are not expanded over so large a surface.

9. That there was no shock of an earthquake felt about this time in the district, nor any appearance of cracks or fissures.

10. That on two former occasions, mentioned in Dr DOUGLAS's letter, viz. in 1804 and 1824, stoppages in the Teviot occurred, both of which were in the winter season.

In reference to this last point, I may add, that I have met with accounts of several other stoppages, besides those noticed by Dr DOUGLAS. On the 25th January 1748, the Teviot, for two miles of its course, remained dry during nine hours. On the 11th March 1785 the river was dry for two hours, and the phenomenon occurred again eight days afterwards. On the 25th January 1787 there was a stoppage for four hours. These four stoppages, it will be observed, were also during the season, when frosts and east winds are known to prevail in this country.

(2.) The next river, the stoppage of which I shall allude to, is the CLYDE. On this subject I corresponded with Mr R. LOGAN, surgeon, at *New Lanark*, who addressed to me two letters, dated 24th December 1838, and 21st January 1839.

Mr LOGAN, in his first letter, states, that the watchmen of the New Lanark mills had their attention first attracted “to the state of the river about 2 A. M. on the 27th November, by the usual noise of the adjoining fall (Corra Linn) having ceased.” “The wind had been blowing from the east for several days, and, about twelve at night, it rose to a stiff gale.” “There was not the slightest indication of the stream having been absorbed by any fissure in the earth; and

it was not till about seven in the evening that there was a sufficiency of water to turn the machinery."

In his second letter, Mr LOGAN repeats, that "the waters of the Clyde were entirely absent from 2 A. M. till 6 or 7 P. M. In the middle of the day, when I crossed by the bridge, a mile below Lanark, the stones in the bed of the river were so bare, that any one might have crossed *without wetting their feet*. I had intelligence of the river being in the same state, for at least twenty-five miles up the stream, and ten or fifteen down."

These letters describe the state of the Clyde in the *lower* part of its course. That the current was likewise arrested in the river near its source, appears from a letter handed to me by Professor FORBES, written by the schoolmaster of Crawford, through which parish the Clyde in the upper part of its course flows. He states that, in that high district, the Clyde was dried up on the morning of the 27th, and was crossed by several persons dry footed, and that the river did not regain its usual size till 3 o'clock P. M. That the rivers Daer and Powtrail, which join the Clyde in the south part of Crawford parish, as well as all the rivulets and feeders there, were remarkably low,—the cause of which was supposed by the inhabitants of the district to be the severe frost of the preceding night. This writer adds, that, during the winter of 1837–8, when the frost lasted continuously for six weeks, and when the thermometer was greatly lower than it was in November last, the Clyde could in no place have been crossed dry footed.

A letter (sent to me by Messrs CHAMBERS, publishers of Chambers' Edinburgh Journal), from the miller of Hyndford-mill, (situated about three or four miles above New Lanark), states that, "on the morning of the 27th November, the water in the Clyde was flowing in its usual manner, until about 6 A. M., when it began to subside rapidly, and shortly after almost ceased to flow. The frost was very severe at the time, accompanied with rather *high wind*. The channel of the river continued nearly dry, until between 12 and 1 o'clock P. M., when it began to flow."

This person adds, "that, during a severe frost, water freezes rapidly *at the bottom of the strongest current*, and the frozen particles accumulate *so rapidly, under certain circumstances*, as to present a complete barrier to the flowing of the water. I have (he says) several times been forced to stop the mill, on account of the opening *under the sluice becoming quite closed up*."

From these different letters, it appears,

1. That the River Clyde, from its sources down to ten or fifteen miles below New Lanark, was, amongst with most of its tributaries, almost entirely dry.
2. That the total desiccation appears to have continued from nine to ten hours, and that the period when the current began to stop, to the period of its again flowing, was about sixteen or seventeen hours.

3. That, at New Lanark, the average width of the current is from thirty to forty yards, and its average depth from one and a half to two feet.

4. That, during the night of the 26th, there was a severe frost, accompanied by a stiff gale from the east, from which quarter the wind had blown for some days previously.

5. That, on the morning of the 27th November, at daybreak, there were accumulations of ice in the river, and especially on the bands of rock crossing its channel.

6. That the river was, on the 26th November, rather above its average level, and on the 28th it was flooded and muddy, though no rain had fallen in the interval.

7. That similar phenomena occurred in the tributaries of the Clyde, and that some of the minor springs were dried up, whilst the larger springs had their supply diminished.

8. That there was no appearance of any fissures near the channel of the river.

9. That the Clyde, in the upper part of its course, flows in a NE. direction.

10. That, besides this recent stoppage, four others had occurred in the Clyde between 1813 and 1837-8, all of which were in winter, and during the prevalence of severe frost.

I may add to these instances of stoppage, the one previously mentioned, which occurred in January 1787, on the day on which the shock of an earthquake was felt to the north and east of Glasgow.

(3.) The only other river the desiccation of which attracted particular attention is the NITH.

The general nature of the phenomenon, as observed in this river, may be judged of from the following extract from a letter, written to me by Mr THRESHIE of Dumfries :—

“ I learn indirectly from Mr SMITH of Dalfibble, a most respectable man, that, on that day (the 27th November), he crossed the river a little below Drumlanrig, in the forenoon, and found the river so void of water, that, with a stout pair of shoes, he could have crossed without wetting his feet ; and recrossing in the afternoon of the same day, the river took his horse nearly to the belly, at the same place, and there had been no rain, or appearance of rain, and the circumstance struck him much. Farther, about four miles farther down the river, two persons crossed on foot, to their surprise, at the ordinary ferry ; and found in the afternoon the boat, as usual, necessary. Much higher up, or below these two points, no particular change seems to have been remarked.”

The most distinct and detailed account I have received in regard to this river is from JAMES SHAW, head-gamekeeper to the Duke of BUCCLEUCH at Drumlanrig.

The letters which he has written me on this subject, prove him to be a zealous and most intelligent observer. Mr SHAW is already known to this Society and the public, by his experiments and speculations on the parr and on the fry of salmon, of which an account was read here last session by Mr STARK. The researches which for many years Mr SHAW has carried on to ascertain the nature and habits of these fish, have caused him to pay particular attention to the state of the rivers in his neighbourhood, on which account, he was peculiarly qualified to afford information as to any peculiarities in the state of the Nith and its tributaries.

From these letters of Mr SHAW, it appears,—

1. That, previous to 27th November, no rain had fallen in the district drained by the Nith and its tributaries for three weeks, and that the waters in these rivers were in consequence extremely low.

2. That, though the Nith was almost entirely dried up between Sanquhar and Enterkinefoot, this was owing to a stoppage of the waters, which took place in the *higher* parts of the river, and especially in its tributaries.

3. That, though the caulds and damheads on the Nith and its tributaries were encrusted with ice, the disappearance of the waters took place in parts of the rivers situated *above* the caulds.

4. That the phenomenon was most striking in those tributary streams, which flowed from the *highest* level, and the waters of which were the most expanded and exposed, by flowing over shallow channels unsheltered by trees or brushwood; and that, on the other hand, it was least developed in the Minnick, a river which has generally a temperature above that of the Nith, the Crawick, and the Euchar, which were arrested.

5. That the waters disappeared from the higher parts of the rivers, before they disappeared from the lower parts.

6. That the wind blew strongly on the 26th, and morning of the 27th, from the east, and was very keen and parching.

7. That the course of the Nith above Enterkinefoot is from the east, as well as that of its tributaries, in which the stoppage or desiccation was most observed.

(4.) I have now given the substance of the information procured by me, regarding the desiccation or disappearance of the waters from the channels of the rivers Teviot, Clyde, and Nith. Before submitting any views of an explanatory nature, perhaps I may be permitted to conclude the above narrative of facts, by mentioning some other Scotch rivers, in which the same phenomenon was observed on the 27th November, and also in former years.

I have a letter from the schoolmaster of Ettrick, stating, that, on the 27th November, the *Ettrick*, at about eight miles from its source, was dried up. It is there usually from ten to twelve inches deep. The desiccation was observed about

the middle of the day, and continued some hours. The thermometer at 10 P. M. on the 26th was 28° Fahr., and at 8 A. M. next morning it was 30°.

The river *Tay* at Perth was observed, on the 27th November, to have had its waters greatly lowered;—my informant states, to the amount of from three to four feet in depth. Attention was drawn to the circumstance, in rather a curious way. A new water-engine had been, last autumn, contracted to be erected in Perth, for driving a saw-mill. It so happened, that the 27th November was the day fixed for trying the machinery, before it was taken off the hands of the contractor. The water-wheels were set in motion by the stream about 9 A. M., and they went very well for about an hour, when they suddenly stopped. This excited surprise, as the wheels had been erected and fixed about a month before, when the water in the river was particularly low; so that, when the wheels stopped, there was an apprehension of some fault in the machinery. But it was soon discovered, to the great satisfaction of the machine-maker, and I may add of his employer, that the cause of the stoppage lay not in the machinery, but in the river, the waters of which had subsided, and left the wheels high and dry. My informant (who is the owner of the saw-mill) states, that this want of water continued till 2 o'clock P. M., and that at 3 o'clock there was current enough to set the wheels again in motion. He adds, that the frost at Perth had been slight during the previous night; but in the higher grounds, at least, the frost must have been more severe, for, at Kinfauns, the thermometer had sunk through the preceding night to 28°.

These are the only other rivers in which (so far as I have heard) the same phenomenon was observed, which occurred (though much more strikingly) in the Teviot, Nith, and Clyde, on the 27th of November.

I should add, that, *on the 28th January last*, another desiccation, but to a more limited extent, happened in the Teviot and in the Ettrick. At Maxwell-heugh Mill, near Kelso, the bed of the Teviot again became dry. On this occasion, at least, the phenomenon may be accounted for, by the current having been entirely obstructed at Ormiston Mill, by a dyke or barrier of ice formed along the lip or edge of the cauld; for above Ormiston Mill, the phenomenon was not observed. On the same day the river Ettrick, near the schoolhouse of Ettrick, was likewise reduced to about one-tenth of its usual size.

With regard to stoppages in other rivers at former periods, I shall notice them very briefly, and shall do so in chronological order.

The *Kirtle*, a river which runs from Dumfriesshire into the Solway Frith, stopped, on the 17th February 1748, for five hours: it stopped again two days after for nine hours, and its channel was dry along seven miles of its course.

The *Sark* (a river which flows into the Eden near Carlisle) dried up near Phillipston, in the parish of Kirkandrew, on the 20th February 1748.

On the same day the *Liddell*, which joins the Esk near Langholm, dried up

near Penton, in Kirkandrew's parish. The Liddell is there usually from sixteen to eighteen inches deep.

The *Lyne*, near West Linton, on the confines of Peeblesshire and Mid-Lothian, stopped likewise on the same day ; and again on the 25th February in the same year, viz. 1748.

The *Esk*, near Langholm, stopped and remained dry for six hours, on 23d February 1748 ; and again, two days afterwards. The *Esk* at this place is, on an average, from eighteen inches to three feet deep.

The *Isla*, near Keith (Banffshire), was, on 28th January 1753, dried up for several hours.

The *Tweed*, at Peebles, was, on the 14th February 1753, entirely dried up from 6 A. M. to 6 P. M.

The *Dovern* was dry on the 2d April 1754, between the Rack and the Surry fords,—*i. e.* for about a quarter of a mile,—and continued so all day. Numbers of people crossed dry shod.

On the 9th February 1755, the river *Beaully*, near Kilmarnock and Kiltarlity, seven miles west of Inverness, became entirely dry during the prevalence of a hard frost.*

The *South Esk*, near Brechin, in Forfarshire, went dry in 1813,—the particular month I have not ascertained. My informant writes, that people might have crossed the bed of the river, in many places without wetting their feet, that the mills were all stopped, that salmon were caught with the hand in the deserted pools, and that the washerwomen who were occupied along the sides of the river in their peculiar vocation, came home with their clothes unwashed, in a state of distress and consternation.

I shall now offer some suggestions, with the view of explaining the occurrence described in the previous part of this memoir.

It must appear sufficiently obvious to any one, who has attended to the circumstances above described, that the frost which prevailed in the south of Scotland during the night of the 26th November, must have, at least, had a good deal to do, in the production of that occurrence. Indeed, the bare fact that, on all the occasions when it was observed in any part of the country, it happened during the six months intervening between November and April inclusive, strongly suggests this conclusion.

One thing appears abundantly evident, that the phenomenon on this occasion was in no way connected with an earthquake, as was at first imagined ; and it is not improbable that, if all the circumstances attending the drying up of the Trent and the Thames, in the 12th century, could be ascertained, they would be found

* For this information, I am indebted to Mr GRIERSON of Dalgado, near Dumfries, who saw a notice of the present memoir in the Society's abstract of business.

not to warrant the explanation which Professor Phillips has suggested. I find that these remarkable occurrences happened, the one in October, and the other in April; so that they occurred at a time of the year, when the frost may have produced them.

But though frost appears to have had, at all events, a principal share in accomplishing the desiccation of the rivers on the 27th November last, it is at first sight not easy to see precisely the manner in which it operated. The frost then was not nearly so intense, or so long continued, as at other times, when, however, similar results did not occur. On the 27th November, the thermometer, in the south of Scotland, did not sink below 25° Fahr. But, in the previous winter, it will be remembered, that, in the south of Scotland, it sunk as low as 5°, and that, for a period of about ten days continuously, it was below 27°. Yet none of the larger rivers stopped during the continuance of this frost, and it was only observed that they were somewhat lower than usual. It is not easy, at first sight, to perceive how the frost acted, so as to produce on this one occasion, phenomena which it failed to produce on other occasions, when it was both more intense and more protracted.

1. It has been suggested, that the ice formed on the lip or edge of the damheads, *arrested* the current, and thus dried up the channel in *inferior* parts of the river. At Ormiston Mill, on the Teviot, a dyke or barrier of ice, from sixteen to eighteen inches high, traversed the entire width of the river, and for several hours prevented the current from flowing towards Kelso. It was observed also, that the formation of this icy barrier was greatly assisted by a strong easterly wind, which, by raising a spray on the lip of the damhead, allowed the water along the line of the cauld to be rapidly reduced to the temperature of the wind.

The effect here described would no doubt be produced, and the explanation may be sufficient to account for the drying up of the Teviot in one part of its course; and perhaps it might answer also for some of the other rivers which run towards the east, and that are crossed by damheads above the places where the stoppage occurred. But the explanation is much too partial and too local to be the true one.

(1.) For, according to it, the same phenomenon should occur almost *every* winter, as there is often a frost accompanied by a high wind, which, whatever be its direction, would blow against the stream of one or more rivers in some part of the country. Now this phenomenon, so far from happening every winter, is of very unfrequent occurrence.

(2.) But, in the next place, the explanation fails entirely in regard to those parts of the rivers where there are no damheads; and it has been seen, that, in the Slitrig, the Euchar, and a number of other rivers, the waters disappeared in those parts of their course which are situated *above* any damhead.

(3.) But even where there are damheads, this explanation is unsatisfactory ; for, if the current was there obstructed, the water should have *accumulated* above them, and, so far from a want of water being experienced by the millers in their mill-leads, there should have been an unusual supply. But all the mills, except one, on the different rivers and their tributaries, were stopped from want of water.

(4.) In the fourth place, if the waters were thus merely arrested for a time, and not abstracted or excluded from the channels, there would be a prodigious overflow, or, in other words, a *tremendous flood*, after the obstruction was removed ; and, moreover, the water would not begin to flow again gradually, but would burst forth with sudden and irresistible impetuosity. These effects, however, are inconsistent with what was observed on nearly all the rivers where the phenomenon occurred. The Clyde only is said to have been a little flooded and muddy on the 28th November,—which can be accounted for by the sudden thaw which, by that time, had taken place. The flow had recommenced, however, the preceding evening, and it came on gradually.

2. Another theory to explain the phenomenon, might be founded on the remarkable fact, that, during the night of the 26th, and morning of the 27th November, there was ice formed in large quantities at the *bottom* of the rivers, which must, to a certain extent, have obstructed the flow of the water.

(1.) But it appears to me, that this would have had a very opposite effect from what occurred ; for, if the velocity of the current is generally diminished throughout the whole course of the river, must it not happen that the waters will be *less rapidly drained off*, and thus, so far from the waters entirely disappearing from the bed of the river, or even diminishing in it, they would appear considerably swollen.

(2.) This effect would be rendered all the more striking, as, by the supposition, the bottom of the river is *raised* by the formation of ice on it. So long as the river continues to draw its wonted supplies from the springs which feed it, the circumstance of ice forming on its bottom, so far from tending to lower the level of the current, would tend only to elevate it.

(3.) Besides, if this were the true explanation, the phenomenon ought to happen *every winter*, and indeed almost *every frost* which occurs ; because I believe there are few frosts, during which ice does not form at the bottom, with even more readiness than on the surface, of running streams.

I may here mention, that the formation of ice at the bottom of running streams, has been frequently observed in the continental rivers, and especially the Elbe. But it was never known that they stopped running, or even diminished in volume, at this period. On the contrary, they were then observed to be generally swollen.

Perhaps I may be permitted to dwell for a moment on the remarkable circumstance, that ice should ever begin to form at the bottom of water. It is known that *ice* is specifically lighter than *water*; and that *water* itself, after it is cooled down to 39° of Fahr., becomes specifically lighter, and rises to the surface. It is, therefore, not easy at first to see how water should, in any case, begin to freeze *from the bottom*; but, nevertheless, there are well authenticated cases of ice forming at the bottom, even when there was no appearance of any at the surface.

This is one of the multifarious subjects which has obtained the attention of M. ARAGO. His views will be found in a paper, the translation of which appeared in Professor JAMESON'S Philosophical Journal for 1833. The phenomena referred to in M. ARAGO'S paper, occurred in the Rhine and the Aar. The facts were fortunately observed by scientific individuals, who watched the gradual formation of the ice in the bed of the river, and ascertained the temperature not only of the air and the ground, but also of the water at the bottom and at the surface of the current. The water was found always to have been cooled down a few degrees below the freezing point; and the water at the bottom, at the surface, and in the middle, always possessed a general uniformity of temperature. M. ARAGO states, that the phenomenon had been observed never to occur in *stagnant* water, but always in running streams, and in those places chiefly where the waters flowed over a bottom bristled with stones, weeds, or other rough substances. The explanation of the formation of ice in these circumstances, is sufficiently simple. From contact with the air, the upper surface of the water is cooled down to the freezing point, or to any given point below it. If the water is stagnant, these cold particles, from their less specific gravity, remain on the surface; but the effect of a current is to intermix the particles belonging to the bottom and the surface respectively, in consequence of which, the whole is reduced to the temperature fitted for congelation. But, it may be asked, why, in some cases, congelation should begin at the bottom and not at the surface of the stream? There are two reasons for this: (1.) From the obstruction which stones and other objects on the bottom give to the current, the velocity is less near the bottom than at the surface, and thus congelation is more possible at the bottom than at the surface; for water, when in rapid motion, is found not to freeze readily. This, then, is one reason why, in streams, ice should form first at the bottom. (2.) The presence of certain bodies in an aqueous medium, is, in all cases, known to facilitate crystallization; than which, a better example cannot be given than water saturated with sugar, which will remain in a state of solution till a piece of wood, or even thread or twine, is dropped into it, when instantly crystals of sugar-candy are formed round the foreign body.

Such is, in general terms, the explanation given by M. ARAGO of the *ground-ice*, which has been observed in the German rivers, and which may be seen any winter in most of our Scotch rivers. It is the kind of ice referred to in the letter

of the miller on the Clyde, already read, who states that it frequently becomes so thick as to fill up the interstice between the bottom of his sluice and the channel of his dam. I believe that this is the origin also of that kind of ice having much the appearance of melted snow, which often floats down our rivers in great abundance, and which, in Dumfriesshire and Roxburghshire, is known by the name of "grue." It is not retained long enough at the bottom to be formed into a solid cake of ice, but by its lighter specific gravity, is able to separate itself from the weeds or mud at the bottom, and rise to the surface of the current.

But to return from this digression, let me repeat, that the formation of this ground-ice cannot, by obstructing the flow of the stream, have the effect of lowering its level, and far less of drying it up. The very opposite effect would follow.

3. It must be obvious from these remarks, that no explanation can be the true one, which assumes that the quantity of water in the rivers on this occasion remained the same, and was only stopped or arrested in its flow. We must seek for some explanation which involves, as a principal element, the actual abstraction or withdrawal of the current from the bed or basin of the river. Now, this condition would be accomplished, if, whilst the supply of water at their sources was stopped, the channels in the lower parts of the river remained open, so as to permit the main current to run off, and thus drain the bed of the river. If the frost acted in such a way, as to seal up and stop the flow of the springs at the fountain-head, and yet allow the stream in the deeper channels to flow as before, then it will not be difficult to see how the phenomenon in question occurred. It is proper, therefore, to inquire whether this theory is at all supported by observation, and whether it can be justified on known principles.

That this proposed explanation is, to a certain extent at least, warranted by observation, is manifest from the letters above quoted; in all of which it is stated, that the rivulets, and even the *springs*, were frozen up and arrested in their flow on the night of the 26th and morning of the 27th November.

That this should have been the case, when the thermometer sunk in the course of that night to 26° or 27° Fahr., is quite intelligible. The only apparent difficulty is to discover in what way the water of the river could be frozen at the sources, whilst it continued to flow in the deeper channels. It has been shewn that the thermometer at 3 P. M. on the 26th stood at 32°, that at 10 P. M. it sank to 26°, and that by 10 A. M. on the 27th November it had returned to 32°. It may be assumed then, that, on the night of the 26th, there was no frost of any degree of severity which lasted longer than eight or ten hours. If, then, the stoppage of the supplies to the rivers in question was affected by the frost, was there any thing which enabled it to produce, during the short period of its continuance, a greater effect on the small streamlets at the main sources of the rivers, than on the main body of the current in the larger channels? It is not difficult to

perceive how the frost on the night of the 26th November, acted so as to produce this effect. It is stated in the letters above quoted or referred to, that, during that night, there was a strong gale from the east; a very unusual circumstance when the temperature is so low as 26° . Now, it is well known that cold, when accompanied by wind, acts very differently than when the air is calm. Bodies exposed to a refrigerating breeze, will be cooled much more rapidly, than when exposed to air of the same temperature in a state of repose. The rate of cooling is, in fact, increased, exactly in proportion to the velocity of the wind. Professor LESLIE has shewn, that, whatever is the ordinary rate of cooling of a body over which a stream of colder air of a certain velocity is blowing, this rate of cooling will be doubled if the velocity of the wind be doubled, and quadrupled if the wind blow with four times its previous violence; or, in other words, it will be reduced to the temperature of the air in one-half or one-fourth of the time which it would otherwise require. "We thence gather (says Sir JOHN LESLIE), that even a moderate wind will quadruple the waste of heat, and that a vehement hurricane is capable of increasing the rate of dissipation perhaps fifteen or twenty times. Hence also the keen impression of frosty winds on our feelings, and their prodigious effects in chilling the surface of the ground. We thus perceive in a strong light the vast utility of shelter."*

The effect, therefore, of the wind on the night of the 26th, must have been to cool down to its own temperature, the objects and places exposed to it with great rapidity. If, at 10 P. M., the temperature of this wind was 26° , we may assume that, by this time, the surface of the ground which it swept over in full force, had been cooled down to at least 29° ,—a degree of cold at which water in drains, streamlets, morasses, and shallow pools, would be entirely consolidated. But it is obvious that this effect would, by that time, have been produced only in exposed or unsheltered places. In the glens and valleys, especially those which were wooded, the surface would not be so rapidly cooled; and if they lay in a north and south direction, there would be additional means of shelter. In proof of this observation, if any were wanting, I might refer to the state of the thermometer at Drumlanrig (in a low sheltered district), and at Leadhills, situated about 1000 feet higher. On the night of the 26th the thermometer at Leadhills was 27° , at Drumlanrig 34° . On Tuesday morning, at Leadhills it was 29° , at Drumlanrig 30° ; at noon, at Leadhills 31° , at Drumlanrig 35° .

We thus see two distinct and separate reasons why the rivers should, on the night of the 26th November, have had their sources frozen up and arrested, whilst their currents in the main channels continued to flow with scarcely diminished rapidity. In the first place, the mere difference of height subjected the sources to a greater degree of cold, than prevailed in the lower parts of the river's course,

* Experimental Inquiry into Heat, p. 284.

it being well known that the atmospheric temperature diminishes in a certain ratio with the height.* In the next place, the temperature of the ground in the higher and more exposed districts would, from the violence of the wind blowing on them, approximate much more rapidly to that of the air than it would do in the lower and more sheltered districts. So that, when the former had fallen to 27° or 28° , the latter would scarcely have reached the freezing point. From these united causes, the water oozing through marshy ground, or trickling along open drains, or in the channels of streamlets on the hills and muirs, would be suddenly congealed and arrested, whilst the larger body of water in the bed of the rivers would continue to flow on unobstructed, and thus effect an entire drainage of the channel.

It is the last of these causes to which, more particularly, I ascribe the phenomenon which has formed the subject of this paper. It is in itself sufficiently simple, and depends on the plainest principles.

The nature of this cause, serves also to explain the unfrequency of the phenomenon. The severe frosts in this country are seldom accompanied with gales of wind. Our gales are generally from the S. or SW., bringing with them warm vapours, which are exclusive of frost; and even when we have easterly gales, there is seldom sufficient dryness to admit of a very low temperature. But, whatever be the cause, it is an undoubted fact, that, in this country, during the prevalence of severe frost, the air is comparatively calm. Under these circumstances, although water at the sources of the rivers must always be more rapidly cooled than in the lower parts of their course, the difference in their respective rates of cooling cannot be nearly so great as in a gale of wind, which affects only the elevated and unsheltered districts. In an ordinary frost, the streams, and especially the springs at the sources of the rivers, are seldom frozen without there being ice formed in the current of the main channel. When the frost continues a sufficient length of time, ice will be formed on the surface of the current where it is deep and sluggish, and at the bottom as well as at the top where it is shallow and rapid. In this way the flowing of the current becomes obstructed; so that, in these circumstances, the river would actually appear more full than usual, were it not that, in consequence of the freezing of the streams at or near the sources of the river, much of the supply of water to it, is cut off. In the case of an ordinary frost, therefore, that is, when it acts with pretty nearly equal effect, both on the sources and on the main current, there will be no drainage of the channel. It is only when the frost is accompanied with a high wind, that it is enabled to affect the sources before it has had time to freeze, the larger bodies of water having a rapid motion, flowing at a lower level, and in a sheltered situation.

There is only one other point necessary to be adverted to, in order to com-

* The temperature sinks 1° of Fahr. for about every 350 feet.

plete the account of this phenomenon. The frost and gale of wind from the east which produced it, ceased on the forenoon of the 27th November. This change appears to have been brought about by the occurrence of a severe storm, or rather a hurricane, which came from southern latitudes. This is the storm alluded to at the outset of the paper, during which the barometer reached a great depression. In fact there were two storms, one following close upon the other, and which reached the British Islands on the 26th and 28th respectively, moving in a northerly direction. On these days, they descended low enough in the atmosphere to sweep over the surface of our islands. That they had previously affected the upper regions of the atmosphere, is shewn by the fact, that, so early as the night of the 25th, the barometer began to sink all over the British Islands, and, notwithstanding the prevalence of the frost and easterly gale of the 26th, which are calculated to elevate the mercury, the barometer continued to sink constantly and regularly until the 29th, when the most violent part of the storm occurred. On the 25th and 26th, therefore, it may be assumed, that the higher regions of the earth's atmosphere over this portion of the globe had become loaded with warm vapour brought by the storm, the upper part of which was in advance of that part sweeping along the surface of the globe; and hence, on the forenoon of the 27th, by which time the storm had approximated to this part of the earth's surface, the temperature suddenly rose, and the easterly gale as suddenly moderated.

Had it not been for the advent of these two storms to this part of the globe, at the exact period now mentioned, our rivers, instead of remaining dry for only twelve or fourteen hours, might have continued in that state for a much longer period, to the inconvenience and injury of many thousands of persons, dependent on the flow of their waters for employment and subsistence.