joined, and the whole formed a bare spit 2 miles long. From the west end of this-sand spit the great Middle Sands extended first southwest 2 miles, with an average width of five-eighths of a mile, and then south-southeast 2¼ miles, the south point bearing south by east nearly 5 miles from Cape Disappointment, and southwest by west 4½ miles from northern extremity of Point Adams. Clatsop Spit extended west one-fourth north from Point Adams to a distance of 2¾ miles, and was composed of several spits bare at low-water; the spit was 2½ miles wide in a north-east and southwest direction at a distance of 1¼ miles from Point Adams; from its northwest point to the east end of the Middle Sands is exactly one mile between the 3-fathom curves; this is the narrowest part of the South Channel.

Chinook Spit ran 5½ miles west half north from Chinook Point; the extreme end of the shoal was about half a mile east three-fourths south from Cape Disappointment; at this point the north channel was barely 400 yards wide between 3-fathom curves. Midway between Chinook Point and Cape Disappointment, the shoal was bare for 1¼ miles at low-water, forming an island lying in very much the same position as Sand Island. Three distinct channels were noticed after passing Swan Island, all of which unite at Tongue Point only to break again with divergent branches in crossing the shoal areas immediately at the entrance to the river; the North Channel hugs the north shore closely for about 7 miles, and then breaks across the Great Middle Bank direct to Tongue Point; the South Channel skirts the south shore for a distance of 7 miles to Tanzy Point, thence across the mouth of Young's Bay, close to Smith's Point, and after passing Astoria turns northeast to Tongue Point; the Middle Channel occupies a line midway between the two former channels, and runs with slight curvature straight to Tongue Point.

During all these changes, exhibited by the several surveys since 1792, it will be observed that the North Channel has maintained itself better than the South Channel (the latter being closed in 1792, from 1841 to 1850, and from 1857 to 1868), and is less subject to change either in depth or direction, owing to the firm and enduring character of the north shore-line. The outer harbor to-day is very much in the same condition it was in the early part of 1857, just before the South Channel was closed by the union of the westward and southward extensions of the Middle Sands with the beach southwest of Point Adams, with this difference, that the spine of the Middle Sands, midway between their western extremity and Sand Island, has been much reduced in height, leading us to anticipate that the waters of the river will again cut through these shoals, as was done in 1850, though in a more northerly direction, or more in the direct extension of the inner reach of the South Channel, and closely approximating to the direction assumed by the single entrance noticed in 1841.

With these facts before me, I am of the opinion at the present time that any improvement designed to be of a *permanent* nature should be applied in the North Channel. In the event that the new channel across the Middle Sands is, contrary to my expectations, not opened at an early day, it is believed that the proper improvements for the North Channel, in connection with an easy and navigable channel to be subsequently made through the interior Grand Middle Banks to the "Three Trees" Point, will consist of a training-wall rising only a few feet above low-water, starting at the outer end of Point Adams, and running north by west (skirting the east side of Clatsop Spit at the inner end), so as to direct the ebb toward the North Channel at the point where the shoal now exists east of Sand Island. This wall may extend 1½ miles to hard bottom at the 4-fathom curve; but its dimensions, exact direction, and

cost, even if such an improvement should be adjudged proper and advisable, I cannot now give by reason of the limited time I have had for studying the question.

The artificial means necessary and fitting to be constructed to maintain a permanent channel across the bar can only be determined upon after a prolonged and careful study of the conditions which affect the character of the harbor. A hasty decision on imperfect data is liable to do more harm than good, and an injury once done may require in its correction a vaster outlay of money than is obtainable, not to speak of the embarrassments which commerce might have to suffer in the mean while, and which cannot be estimated in dollars and cents. This reason causes me, then, to ask permission to defer any recommendations looking to a permanent improvement (accompanied by plans and estimates) until such time as I shall have been enabled to study the problem more carefully and become more familiar with the wants of the commerce which seeks this port. I would recommend, however, an apppropriation of $5,000 to provide for a limited survey and a continuous observation of the currents.

It is not believed that dredging on the bar will be of any value. The season of severe storms covers a period of six months, and the material of the bar is so light and shifting that we may anticipate that a channel dredged during a short period of calm would be filled up during the first succeeding storm. The place is so exposed, too, that the times at which a dredge could work would be rare and of very limited extent, and any dredging so done would not increase the confidence of the pilots. The only remedial measure, it seems to me, is to ascertain the best means of securing the full effect of the ebb through some elected channel, and then let nature undisturbedly work out its own course.

Lieutenant Payson deserves great credit for the energy and judgment displayed in the discharge of the work assigned to him, and for the zeal and devotion with which he labored against the difficulties constantly attending him in the prosecution of the survey.

I am, general, very respectfully, your obedient servant,

G. L. GILLESPIE,
Major of Engineers, Brevet Lieut. Col., U. S. A.

The CHIEF OF ENGINEERS, U. S. A.

REPORT OF LIEUTENANT A. H. PAYSON, CORPS OF ENGINEERS.

PORTLAND, OREG., *November* 16, 1878.

MAJOR: I have the honor to submit the following report of operations under my charge for the survey of the mouth of the Columbia River, Oregon. Having, in compliance with a telegraphic order from Washington, dated August 5, reported here on the 10th, I proceeded to Astoria on the 13th, taking with me Mr. D. W. Taylor as an assistant.

In view of the lateness of the season when the work began it was desirable to use all possible haste, and, having secured the services of Messrs. Woods and Wilson in Astoria as additional sextant observers, together with the necessary recorders, leadsmen, &c., two parties were formed: one, to work outside in a bar-tug; the other, within the river in a steam-launch; the sides of the Coast Survey triangle formed by Cape Hancock light, Stevens's flag-staff, and Scarborough Head Beacon being used as base lines. The first week was spent in the erection of the necessary signals, and in fixing their position and that of certain prominent natural objects by careful triangulation.

On Monday, the 19th, sounding was begun by both parties, the one on the bar being under my personal charge; the other, under that of Mr. Woods, who had had some previous experience of this sort of work in the Coast Survey. The method was as follows:

The steamer, moving at the rate of from 3 to 4 knots an hour, and kept as nearly as
possible on parallel ranges, was located by two simultaneous sextant angles, every
5 minutes, when moving straight ahead, and additionally whenever a change of
course was made. Soundings were taken every half minute, and, as soon as a posi-
tion had been observed, it was plotted on the chart to enable the chief of party to
watch and correct the position of the tug.

The soundings taken were reduced to "mean of lowest low-waters," as follows: Two tide-gauges were established, one at Astoria and the other on the wharf at Cape Hancock. Both were read every 15 minutes while the work was in progress. The gauge at Astoria was set by careful leveling from a Coast Survey bench-mark on the rocks; the one at Hancock was first set arbitrarily and the height of low-water noted on it every day during the survey. A mean of the differences between these readings and those for low-water on the same days at Astoria was then taken as the difference in level between corresponding marks on the two gauges. The Cape Hancock tide was used in reducing all soundings west of the end of Sand Island; that at Astoria for the rest.

From the outset much delay was caused by unfavorable weather. Large forest fires prevailed throughout Oregon and Washington Territory, and the smoke from these obscured the air at the mouth of the river whenever there was not a strong northwest wind, which in its turn made the sea, especially on the bar, too rough for accurate work.

However, by taking advantage of every opportunity, some hours were secured on nearly every day, and fair progress made until September 7, when the smoke became so dense as to entirely prevent sounding until the 20th. From that time, though much hindered by intermittent rain and wind, we were able to keep on until the 25th, when a southeasterly storm set in with great violence and entirely stopped work until October 3. The inside party finished and was disbanded on the 5th, and the outside party on the 8th, just in time, since a storm set in on that day which continued for nearly three weeks.

The progress from day to day is fully described in my weekly reports to this office. The following is a summary:

Area covered by the survey	44½ square miles.
Length of lines of sounding	821 miles.
Number of determined positions	2,729
Approximate number of soundings	32,000

The current observations, made in obedience to Colonel Wilson's instructions, are described in a separate report.

Every available hour of favorable weather being necessarily employed in sounding, no attempt could be made at the gauging of the river. Had there been time and means at my disposal, however, I should have been at a loss to know how to set about it. Complicated as the problem is in a river, remaining substantially at the same level for days at a time, and with its current always in nearly the same direction, it becomes infinitely more so when we have to deal with an ever-varying tidal flow in an estuary into which is daily poured an immense volume of fresh water from the river.

The few current observations taken, although the river was at a low stage, show in a marked way the irregularities which have been often observed before in similar places. Generally there is no defined slackwater, the currents of the tides swinging around till they cannot be distinguished from those of its successor; the surface and sub currents, particularly at the first of the flood, make a large angle in direction with each other; the flood of heavy salt water makes up along the bottom, long before the surface ebb has ceased to flow; and, finally, the changes from ebb to flood or flood to ebb begin at widely different times in the channels, on the sands, and at the different depths.

Under these circumstances any reliable measurement by direct current observations seems well-nigh, if not wholly, impossible; and the only even tolerable appoximation would probably be found in a computation based on the river's discharge above the tidal influence and the volume of the wedge-shaped body of salt water pushed up under it by a flood-tide. For even this a far more extended knowledge of the river would be necessary than that furnished by any survey of its mouth.

Since the completion of the field-work, I have been engaged with Mr. Taylor in reducing and plotting the notes on a scale of $\frac{1}{20000}$. The rough draught of the map is now completed in ink.

But one previous *detailed* map is available for comparison; it is that made from a survey by Captain Jessen, under Colonel Wilson's direction, in 1876.

The following is a brief description of the present river's mouth, and the changes which seem to have taken place:

The distance from Cape Hancock or Disappointment to Point Adams is about 6 miles, which is virtually the width of the entrance.

From the latter point a broad sand, called Clatsop Spit, makes out almost directly
toward the cape for about 2½ miles, thus reducing the available width by nearly one-
half, since, though the sand is covered by from 1 to 2 fathoms, the sea breaks heavily
over it in nearly all weather. About midway between the end of the spit and the
cape, a little inside of the line joining them, is a constantly shifting sand island, just
now nearly 1½ miles in length by from 1,000 to 1,200 feet in width.

From the western end of this island the submerged bank, known as the Middle
Sands, extends within the 3-fathom curve in a direction a little south of west for
nearly 4 miles; and thence, turning south a sharp angle, runs for about the same dis-
tance further, substantially parallel to and overlapping Clatsop Spit.

Finally, still another sand, called Peacock Spit, or the North Breakers, extends to
the south toward the Middle Sands from Cape Hancock.

There are, and as far as known always have been, two ship-channels out of the
Columbia River. At present they separate at the eastern end of Sand Island; the
first, or North Channel, passing between the island and the cape, and thence out over
the bar between Peacock Spit and the Middle Sands; the second, or South, at first
nearly east and west between Clatsop Spit and Sand Island, and thence about due
south between the spit and prolongation of the Middle Sands described above.

The South Channel, which is the one principally used, has a depth of 20 feet on the bar at "mean low-water," though the tide sometimes falls 2 feet lower than this, and a minimum width, between the 18-foot curves, of about ¾ of a nautical mile.

The North Channel, though the narrower, has 23 feet over the bar, but at the inner end of Sand Island there is a bad shoal with but from 16 to 17 feet of water on it.

It will thus be seen that, though much obstructed by sands, the mouth of the Columbia affords now, and probably always will, a sufficient depth for the ordinary needs of commerce in tolerably smooth weather.

What makes the bar such a formidable barrier that sailing-vessels are sometimes detained weeks and steamers days, while waiting for a chance to cross, is the tremendous sea, which, under the influence of the prevailing southerly storms of winter, breaks in and out of the channels, completely across the mouth of the river. Though caused by winds much more southerly in direction, such is the tendency of that portion of the wave which is in deep water to travel faster than its inshore end, that the heaviest seas are projected upon the coast approximately normal to the line adjoining Point Adams and the cape. Hence, a vessel going out is head on to the sea in the North Channel, and broadside on in the South. This would seem to the advantage of the former, but there is a consideration which generally makes it the reverse, namely, that a vessel pitching heavily requires much more water under her to insure against her striking than if she were rolling. Partly, perhaps, from this reason, and also on account of the shoal at the inner end of the North Channel, the South, as stated above, is the one in general use. As an additional reason, I am inclined to think, from my own experience and what I could learn from others, that the sea is generally not quite so heavy in the South Channel, the Middle Sands forming, as it were, a kind of breakwater; while, finally, it is the more direct way for most of the traffic out of the river which seeks to go to the south.

To facilitate a comparison, the 18-foot curves, which may be considered as the determining lines of the bar, have been plotted over each other from the surveys of 1876 and 1878. They are shown in the tracing transmitted herewith. An examination shows the following to be the principal changes which have taken place during the two years:

1st. Clatsop Spit has extended nearly a quarter of a mile in a northwesterly direction toward the elbow in the Middle Sands, and has been largely cut away on its western side, or that toward the South Channel.

2d. The western end of Sand Island has made to the north and west toward Cape Hancock nearly the same distance.

3d. That portion of the Middle Sands lying east and west has moved north about 600 feet and slightly decreased in width.

4th. The part lying north and south has made considerably to the south and east; that is to say, over toward Clatsop Spit.

5th. Peacock Spit has worn away to the north more than the Middle Sands have moved in the same direction, and, consequently, the outer part of the North Channel has become straighter and wider.

6th. The inner part of the North Channel, north of Sand Island, has narrowed perceptibly and shoaled up nearly 3 feet in some places, while its outer portion is deeper over the bar by about the same amount.

7th. In consequence of the erosion of the west side of Clatsop Spit and the extension southeast of the Middle Sands, the main course of the South Channel has been deflected considerably to the east or bent back upon itself. Though the minimum width of that channel, between the south end of the sands and the spit, remains about the same as in 1876 (¾ nautical mile), its axis has shifted at that point fully half a mile to the east. The ruling depth over the bar remains about the same, but the later survey shows an absence of certain deeper places in the shoalest portions which existed in 1876.

Upon examination it will be seen that all of these changes tend to produce one chief effect. The northern extension of Sand Island, and the shoals about it, has forced the ebb into a wider detour to get out of the North Channel, which has consequently narrowed and shoaled toward its inner end. Yet we find it wider and deeper outside; hence the conclusion is necessary that more water has crossed into it over the Middle Sands.

This inference is also strengthened by the more circuitous course of the South Channel, its slightly inferior depth, the decreased width of the separating neck of the sands, and the erosion of Peacock Spit.

Owing to the fact that the sea breaks here in 2 fathoms in almost any weather, it is generally impossible to fix that contour very closely, and consequently to make as accurate a study of the changes as desirable, but it seems evident that while, in 1876, the 2 and 3 fathom curves here were close together, the former have now receded to inclose a narrow spine or ridge, with nothing less than 11 feet on it, close to and sloping steeply toward the North Channel, and broken, moreover, by two gaps with from 13 to 14 feet of water through them.

It is certain that the bar-tugs now cross here freely at nearly all stages of the tide when it is smooth, which they were not in the habit of doing in 1876, and that this fall, I believe, for the first time, sea going vessels in ballast have been sailed in by the North Channel and thence over this neck in the sands into the South, thus being enabled to dispense with the steam towage which would have been necessary had they been obliged to make the turn up to the north around the cape.

It can, therefore, I think, be safely asserted, that during the past two years the tendency of all the changes has been toward the breaking out of a new channel connecting the present north and south entrances over the Middle Sands. Though it is of course impossible, on such scanty knowledge of the complex causes which are at work, to predict that such a change will take place, it is certainly not unlikely to occur, and if it did, would be at first of great benefit to navigation.

That such benefit, however, would be only temporary in its character there is little doubt, for the following reasons: The bar of the Columbia is of pure sand, that is, a wave bar, caused by the opposing action of the river and the sea, without the addition of any sedimentary matter from the stream. In places of similar character, which have been longer and more carefully observed, there has been noted a sort of cyclical change in the entrances.

Under the influence of prevailing winds and seas, the sands, moving always in the same direction, deflect the channel-ways until they are no longer able to withstand the increased pressure brought to bear upon them, when the water breaks through, either suddenly or gradually, to take its original direction and resume its movement as before. Hence, were the North and South Channels closed to-day, and a clear passage left straight out to sea in the prolongation of the river's course, it is quite certain that natural causes, if left unhindered, would, in course of time, reproduce substantially the same conditions which exist at present.

Additional information is to be had from the Coast-Survey chart of 1868 and the annual surveys of Sand Island, which have been made since the same date. From the latter it appears that the southern shore of the island has moved fully 2,000 feet due north. What was, ten years since, dry sand has now 9 fathoms on it at low-water. Its area has not materially changed, though its form has become narrower and longer, with a disproportionate extension of its western end to the northwest or toward Cape Hancock; the advance in this direction in the ten years being about 3,200 feet.

From the Coast-Survey chart we see that the form and area of Clatsop Spit remain about the same now as then, though its axis has shifted slightly to the east. The channel width between its end and Sand Island has not materially varied, but, in the form of the Middle Sands there has been a large and striking change. In 1868 there was but a slightly-marked elbow in the sands, their general course being in a gentle curve to the southeast. We see now the two portions forming a deep pocket or bight, making actually less than a right angle with each other in general course, in doing which their southern end, without much gain to the south, has moved over toward Clatsop Spit until the southeastern limit of the 18-foot curve is now a nautical mile nearer the light on Point Adams than in 1868; while the width between these curves on the sands and spit has narrowed from nearly 2 to less than $\frac{3}{4}$ of a nautical mile at the southern end of the sands.

The effect of this bending in of the course of the South Channel is plainly shown in the depth. In 1868 there was a good 4 fathoms over the bar; now a scant 20 feet. Forking at Peacock Spit, we find that it has been cut away to the north more than three-fourths of a nautical mile.

Since 1868 the outer part of the North Channel has deepened a little; its width has not materially changed.

The minor portion, north of Sand Island, has a good deal less water in it now than

then; while in the earlier chart we find no traces of the shoal now existing at the inner end, over which there was then $3\frac{1}{2}$ fathoms.

All these facts seem to show, therefore, that the direction and effect of the movements have been practically the same for the last ten years as during the past two.

In conclusion, I will offer as a suggestion the advantage which would arise from making an examination of the bar each spring. It need not be a detailed survey, since the expenditure of $1,000 and a week or ten days' time would suffice to gain a very good idea of the existing conditions.

Such an examination, independently of its use in the study of the place, would be of great advantage to commerce.

No one familiar with the shifting nature of these sands would put any confidence, as an aid to navigation, in a map made before the previous season of winter gales.

Respectfully submitted.

A. H. PAYSON,
First Lieutenant of Engineers.

Maj. G. L. GILLESPIE,
Corps of Engineers, U. S. A.

CURRENT OBSERVATIONS AT THE MOUTH OF THE COLUMBIA RIVER, OREGON, DURING SEPTEMBER AND OCTOBER, 1878.

During the survey there was but little opportunity for current observations, almost every hour of favorable weather being necessarily used by the sounding parties. Advantage was taken, however, of a few days when the smoke was too dense for other work, by finding the buoys and making the observations at them. The results are, of course, imperfect and fragmentary, serving little other purpose than that of showing the direction of the main flood and ebb currents at the stations occupied.

The measurements were made with double cans of the size and form used in the Coast Survey. They were cylinders of galvanized iron, 13 inches long by 11 inches in diameter; the upper one terminated by two cones, 6 inches in altitude; the lower coned only at the top and having its base a plane.

The vertices of the cones at the bottom of the upper and top of the lower can being joined by a cord, the combination was weighted by gravel till it floated with the base of the uppermost cone at the water's surface. Each can then presented the same cross-section to the action of the current, and the theory is, in consequence, the combination will move with a velocity which is a mean of those in which the upper and lower cones find themselves.

Thus, calling the surface velocity a, the velocity of the connected cans b, and the required subsurface velocity x, we shall have $b = \frac{a+x}{2}$ and $x = -a$.

The cans were logged from the stern of the steamer, and the surface velocity determined for each observation by a pole about 6 feet long, weighted to stand upright in the water, and also logged.

Though this method is open to many objections, it was the only one which could be resorted to, since it was, of course, impossible to observe free floats from stations on shore, while the roughness of the water prevented the use of meters.

The points occupied are plotted on the tracing marked A.

The course and velocity of the surface current at each are shown throughout the time of observations on the tracings marked from 1 to 8, inclusive.

Measurements were only made at the surface and greatest depth at which the connected cans would run out without touching.

The following is a brief description of the results at the several stations:

Black Buoy off Stevens's Wharf, September 11.—Period of observation: flood, 2 hours and 38 minutes; ebb, 4 hours. The main flood is directed into the deep channel along the shore from Stevens's Wharf to Tanzy Point. Magnetic direction from east by south to east-southeast. The main ebb is nearly exactly opposite, setting toward the eastern end of Sand Island. Magnetic direction west-northwest. But little ebb passed over Clatsop Spit. High-water at Cape Hancock at 12 m. 6.5 feet above mean low-water, but the tide did not begin to turn at station till 30 minutes later. No slack, the current swinging gradually round by the north. Maximum flood velocity at surface, 5.6 feet per second; maximum ebb, 4.8 feet. During the strength of the flood the divergence between the surface and subsurface current was considerable, the former remaining to the right or south of the latter. The maximum angle was between 30° and 48°.

During the first ebb the surface current remained at the right or north of subsurface, the angle at one time reaching 30°. After the ebb began running full strength their directions became identical. Throughout the day the surface current was considerably stronger than the subsurface. The turn of the tide took place at the same time in both.

September 13, *same station.*—Flood, 3 hours; ebb, 2 hours and 31 minutes. This day showed same directions for flood, ebb, and turn as the preceding. Throughout the flood and first of the ebb, the surface current remained to the right of the subsurface, but the divergence was not so large as on the 11th. During main ebb, their directions were the same. High-water at cape at 1.15, 7 feet above mean low-water. Surface current began to turn at 1.50, the subsurface about 10 minutes later. Maximum flood current, 4.8 feet. Maximum ebb, 5 feet. Subsurface all the time less than surface.

September 23.—Turn from ebb to flood and ebb 4 hours and 10 minutes. Direction of turn and main ebb same as in preceding two days. No divergence worth mentioning between surface and subsurface currents. High-water at cape 10 a. m., 6.1 feet above mean low-water. Turn 30 minutes later, preceding at surface by about 15 minutes. Maximum velocity at surface 5 feet per second. Subsurface velocity always the lesser.

September 12, *mid-channel buoy east of Sand Island.*—Flood, 4 hours and 22 minutes; ebb, 2 hours and 31 minutes. The first of the flood set directly toward Scarborough Head, about east by north, and continued so till after reaching its maximum velocity, 2.8 feet. During the hour and a half before the turn, the current, slacking all the while, was directed toward the middle of the river, about east by south.

High-water at the cape 12.45 p. m., 6.9 feet above mean low-water. The turn began about 1 p. m. and took place by the south, the course swinging around without any absolute slack. At 2.30 the ebb had reached its main direction, about west by north, which it held till the close of observations, attaining a maximum velocity of 5.6 feet per second.

Throughout the day, the subsurface current at 18 feet was considerably weaker than the surface. They both turned substantially at the same time. During the last of the flood, without there being any very well marked or continuous divergence, the surface current was directed more toward the middle of the river than the subsurface. During the main ebb their courses were identical.

September 19, *black buoy in North Channel.*—Flood, 3 hours and 10 minutes; ebb, 3 hours and 50 minutes. For the first hour the coarse of the ebb was about west by south, slackening from the maximum 2.4 feet to about 2 feet; it then shifted to west and retained that direction for 30 minutes, changing suddenly back to west-southwest, where it staid 2 hours, slackening gradually to 8 feet. Ten minutes later, at 12.50 p. m., the course was south by west, with a feeble current of 4 feet, and immediately after it became imperceptible. It was low-water at the cape at 10.30; hence the ebb continued running more than 2 hours afterward. At 1 p. m. there was a flood current of 5 feet, moving north by east, or exactly in an opposite direction to the last ebb, which had preceeded it by only ten minutes.

The flood worked gradually to the southward, increasing all the while till 2.30, when it reached its main direction, about east-northeast; maximum velocity, 1.6 feet. It was high-water at the cape at 4.15. At 4 the flood began to work rapidly to the south, and at 4.15 the last feeble flood current of only 5 feet was running a little to the west of south, or almost precisely in the same direction as the last ebb. Throughout the first of the observations the subsurface velocity at 25 feet was less than the surface, and at 11 a. m. it became imperceptible. Soon after it became evident by the behavior of the cans that the young flood was making up along the bottom, though it was not possible to measure its course nor velocity. This condition of things continued till the surface current changed, as described above, when it could be seen that the subsurface made a large angle (nearly 80°) with it, and had in fact nearly reached its normal direction. In about an hour the surface current working to the south overtook it, and from there their courses remained the same.

September 14, *Station B.*—Flood, 5 hours and 38 minutes; ebb, 1 hour and 54 minutes. The observations began at 9 a. m. Though it was low-water at the cape at 8.30, the surface-ebb continued running out till 9.20; course, due west over the Middle Sands. From then till 10 a. m. it was slackwater at the surface when the young flood began to set in east by north. It continued to run with a general direction east-northeast till 2.30 p. m., reaching a maximum of 3.2 feet per second, and then becoming slack at that time. High-water 1.45 p. m., 6.9 feet above mean low-water. At 2.40 the first of the ebb began south by west, and ten minutes later was running in a general course of west-southwest, which it kept till the close of observations at 4.30, attaining at that time its maximum velocity of 6.7 feet per second.

When the observation began, at 9.30, with an ebb of 1.3 feet at the surface, the subsurface current at 60 feet was running flood in a nearly opposite direction, northeast, with a velocity of 2.7 feet per second. It continued with about the same swiftness and direction through the surface, slack, and till the latter changed to flood. The first flood surface currents made a large angle (some 30°) with the subsurface, being to the south in direction and much inferior in swiftness. This continued till 12 m., when the subsurface got to the southward of the surface, remaining so by a constantly increasing angle, and with higher velocity, till the second surface slack at 2.30. The subsurface continued to run flood for 30 minutes longer, and then, after a stand of less than 10 minutes, began ebb with exactly the same direction as the surface flow, but

considerably inferior velocity. It kept gaining, however, and at 3.10 was again swifter than the surface, which state of affairs continued until at the close of the day it was running 7.5 feet per second, with a surface current of only 6.7 feet.

September 16, *Station C.*—Flood, 4 hours 30 minutes; ebb, 1 hour and 30 minutes. The observations began at 9.30 during the last of the ebb, low-water at the Cape having occurred more than an hour before that time. The course of the surface-current was west by south. At 10 a. m. it became slack, and remained so till 10.30, when the first flood began to run northeast by east; from 10.40 a. m. to 3 p. m. it varied in direction between east by north and east by south, reaching at 12.50 its maximum of 3.46 feet per second. High-water at Cape 2.45 p. m., 6.7 feet above mean low-water. At 3.10 p. m. it began to swing about by the south, without any perceptible slack, and at 3.50 had reached its maximum ebb direction (southwest), which it held with remarkable steadiness till the close of observations at 4.30, attaining a maximum velocity of 2.6 feet per second at that time.

In the morning, during the last of the surface-ebb and slack, preceding the change to flood, there was evidently a subsurface flood-current at 50 feet, but not strong enough for measurement with the cans. When the surface first began to flood, it made a large angle with the subsurface, the latter being to the southward and considerably swifter. In less than half an hour their courses became the same, and soon after the surface-current became the more rapid.

When the surface began to change to ebb, the subsurface showed a tendency to pre serve its original course, and followed after it with a divergence varying from 20° to 30° to the eastward, and a much lower velocity.

September 19, *Station D.*—Flood, 5 hours 30 minutes; ebb, 2 hours 3 minutes. The observations were begun on the last of the ebb. Low-water at Cape at 9 a. m. From 9 to 10 a. m. the surface-current ran west ½ south, with velocity decreasing from 3.2 feet to 1.9 feet per second. Between 10 and 11 a. m. it worked gradually from west to northwest, falling to 2 feet per second. From 11 to 11.20, over 2 hours after low-water, it was slack. At 11.20 the first flood began in nearly an opposite direction to the last ebb, namely, southeast by south. From then till 11.50 it worked steadily north, running at that time northeast by east. It then settled back to its main direction, about due east, and reached its maximum velocity of 2 feet per second at 2.10 p. m. High water at Cape at 2.45; 6.7 feet above mean low-water at 2.40. The current began to veer irregularly around to the south, decreasing to 1 foot per second, at 4.10 p. m. At 4.30 its velocity had increased to 1.3 feet per second, and its course had become due south. Hence there was no actual stand, since the last direction was, evidently, the first of the ebb. From 9 to 9.20 a. m. the surface and 26 feet subsurface were the same in direction. At 9.30 the subsurface had begun to feel the influence of the flood and had moved off to the north, so as to make, with the surface, an angle of about 40°. This divergence continued to increase until the surface became slack, when the subsurface was running about northeast with a velocity of 1 foot per second.

Throughout the whole strength of the flood, the direction of the surface and subsurface currents remained nearly at right angles with each other; that is, while the surface-flood coming in over the Middle Sands was running directly into the mouth of the river, the subsurface current, coming up through the south channel, was flowing northeast into the deep water south of Sand Island.

When the surface-flood began to turn to the south the subsurface current followed, still maintaining its divergence, until the former had become definitely ebb and begun to increase, when their courses suddenly became identical.

Respectfully submitted.

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