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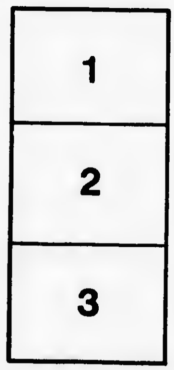
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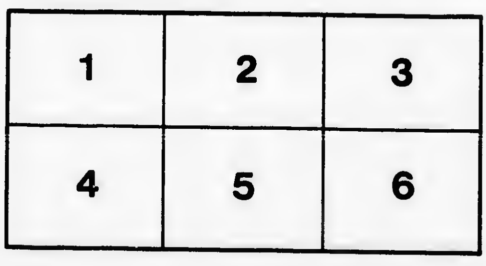
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Currents and Shore Processes in Lake Ontario

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MONTREAL, QUE.

(Read before the Engineers' Club, Toronto)

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Currents and Shore Processes in Lake Ontario

By Alfred W. G. Wilson, Montreal.

Introduction:—Within the last twenty-five or thirty years there has gradually grown up, as an offshoot from the Science of Geology, a science whose specific object is the systematic study of land forms, their characteristics, origin and history—the Science of Physiography. Under the impetus of new methods of investigation there have been marked advances made in our knowledge of the history of land forms and their processes of growth and disintegration. The results of these investigations have a very direct bearing on all engineering operations which attempt to guide or control those natural processes which produce or modify topographic forms.

Shoreline processes and shoreline forms have been investigated by many observers, and many important papers have been published. It is only about ten years ago, however, that the subject was systematized by the recognition that there are progressive stages in the development of shorelines and shoreline topography; that initial forms, characteristic of newly formed lake basins or of sea coasts recently elevated, are followed by a sequential series of forms characteristic of later stages of the life history of shorelines, until extreme old age is reached.* The life history of shores, the processes which are involved in the formation of shore zones and the later development of any given shoreline have all a very direct bearing on the construction and maintenance of docks and harbors on all our large water bodies, whether lake or ocean, on the preservation of coast lines, and to a certain extent on water supply and sewage disposal.

The problems presented by Toronto Harbor, Toronto water supply and sewage disposal form no exception to the generalization, and it is because of their bearing on these problems that the data given in this paper are here presented.

Only a summary of the results of a study of the shorelines, and shoreline processes on lake Ontario can be given here, but, I wish especially to emphasize the fact that the

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*Gulliver, Shoreline Topography Proceedings of American Academy of Arts and Science, vol. 34, 1899.

processes described are world-wide in their operation, and that the land forms developed on the shore of the Great Lakes are forms characteristic of a certain stage of shore development wherever shorelines occur.

Geologic Processes on the Shores.

Movements of the Lake Waters:—Nearly all geologic processes on the shores of any water body are dependent on the movements of the water itself. The movements of the water of the Great Lakes are of four types—tide, seiche, current, and wave.

While the existence of periodic movements of the water of the Great Lakes corresponding to the tides is known, the amplitude of this movement is very small and in the present discussion it does not need to be considered. On all bodies of water exposed to the action of winds three distinct types of movements are developed—the seiche, the current and the wave. The current movement may also be developed directly or indirectly by gravity. All shore processes—degradation, transportation, aggradation and sedimentation, on a significantly large scale at least, must be through the operation of one or more of these movements, either acting separately or in conjunction.

The Seiche:—A wind blowing continuously for a considerable period of time in any given direction tends to force the surface water ahead of it and to pile it up on the lee shore. As a result the equilibrium of the water body as a whole is disturbed and a series of oscillations of the water body as a whole are set up. The amplitude of the seiche oscillation is directly dependent on the wind velocity and persistence in a constant or nearly constant direction. Its rate of propagation has been proven to be a function of the measure of the length of the water body in the direction of motion, and of the cross-section normal to this. As an agent of transportation when acting directly it is practically powerless. Acting indirectly through the operation of currents passing through narrow channels it may possibly be able to move some very fine materials, such as clay, held in suspension.

Seiche oscillations caused by strong easterly or westerly winds have at times a very marked effect on the depth of water in the harbors at the east and west ends of the lake. In the Bay of Quinte the seiche oscillation is frequently quite well shown and at Napanee a periodic variation of three feet or more is often noted.

Currents:—In 1892 and 1893 the United States Weather Bureau carried out a series of investigations on the distribution of the surface currents of the Great Lakes—bottle floats being employed. In his report on the results of the investigations M. H. Harrington groups the currents of the Great Lakes under four heads:—The body current, a surface current due to the prevailing winds, the return currents and surf motion.*

The body currents and the return currents may be regarded as constant. With these may also be associated the locally constant currents found at points of inflow and outflow of the main streams of the lake—the Niagara and St. Lawrence Rivers. At these points there is a small but constant current, really a portion of the body current of the main lake. Usually these local currents are too weak to be active transporting agents except in the immediate vicinity of the outlets or inlets. At the mouth of the Niagara River the discoloration of the lake water shows that a small amount of fine waste is carried out into Lake Ontario. Two miles off the mouth of the river the coloration has disappeared and the current has been merged with the general drift of the surface waters of the lake. The outer portion of the Niagara River current in Lake Ontario has been found to shift its position with the winds. The waters of the St. Lawrence where it leaves the lake are clear and practically free from sediment.

In Lake Ontario there is a slow general set of the mass of the water towards the outlet, while there is a pronounced vertical movement of the mass of water at the west end of the lake forming a backset eddy. Where, by the action of the wind, surface currents have driven more water to the eastward of the lake than can well pass through the discharge there must be more or less of a return current. In this lake no return current, so well marked as in the other great lakes of the system, has been found. The probability seems to be that in part it breaks up into smaller whirls along the great pockets of the coast on either side of the general current and that a considerable body of water is returned as an undercurrent.

The rate of the general east flowing drift is very slight, probably never exceeding twelve miles per day, more frequently being much less than this. The currents of the general circulation and the return currents are too feeble to

*Currents of the Great Lakes, Bulletin B., United States Weather Bureau, 1894.

transport even the finest sand which occurs along the beaches. They must, however, assist in the distribution of the finest silts and clays over the bottom of the lake.

The currents of streams tributary to the lake only effect the waters a very short distance from their mouths. After discharge, except for the first few yards of their course, the direction that the river water takes in flowing through the lake is determined wholly by the direction in which the lake waters at the point of discharge happen to be flowing at the time. Except in the immediate vicinity of the mouths of the streams in question these currents have no effect in modifying the lake shores.

With regard to the surface currents produced by the prevailing winds, their general direction is the same as that of the wind with which they are associated. A study of the prevailing winds for the lake stations, made by the officials of the United States Weather Bureau, and covering a period of seventeen years, shows that there were on the average 66 per cent. of westerly winds for the whole year. For the months from May to September 56 per cent. were from a westerly direction. For the same period of time a study of the resultant wind directions shows that in 183 out of 204 monthly values and in all the annual values the resultant is westerly.

Out on the open lake the transitory movement of the water before the wind takes the form of a drift, and because of the prevalence of westerly winds this drift is most frequently identified with the easterly flowing body currents of the lake. The drift currents vary their direction with the wind that causes them, usually starting a short interval after the wind has commenced to blow and continuing for some time, often several hours and occasionally several days, after the winds that caused them have ceased. Where this drifting surface water impinges on a shore a longshore current is developed, the direction of the current being dependent on the angle at which the drift impinges on the shore. These currents, which for convenience may be designated wind currents, are seen during wind-storms, and reach their maximum velocity at times of the strongest storms. They are so intimately connected with wave and surf movements that both must be considered together. It is when they act in conjunction that active erosion, transportation, and deposition take place. During a period of heavy storm a longshore current may require a velocity as great as four miles an hour.

The occurrence of undercurrents, moving in a direction contrary to that of the surface current or of the prevailing wind is a common feature. They will be caused wherever in-any part of the lake the water is piled up above the mean level, since the head of water thus raised forces a portion of the water back as an undercurrent. They are also frequently formed when there is a change in wind direction following the development of a strong longshore current. The momentum acquired by the water will often maintain a strong undercurrent a little way off shore, for a long period after the direction of the longshore currents on the surface has changed.

Waves.—The same wind that generates a surface drift which becomes a longshore current where it impinges on the shore also develops waves. At a few points the water of a wave may roll up on the beach at the shoreline and run directly back again, but only at those points where the shoreline is parallel to the wave front. On the shores of the Great Lakes, where the shorelines sweep in great open curves with chords often from 4 to 8 miles in length, the wave front very frequently advances at such an angle to the shoreline that the waves roll up the beach obliquely. Where this happens the water never returns by the same path that it came, but runs off obliquely; so that material on the beach when moved by the waves tends to travel along the shore by a zigzag path, the angle at which the wave strikes the shore determining the angle between any two limbs of this path of travel.

Inter-relations, Waves and Currents:—Along a stretch of lake shore where the waves are impinging obliquely and where a number are always breaking at once, the tendency will be for the waves themselves to generate a longshore current flowing in the direction in which the bisector of the acute angle between the wave front and the shoreline points. This wave-generated current is always accordant with the longshore drift current caused by the same wind, and as they operate together in shore transportation they may be referred to simply as the longshore current.

After the wind which has started the waves and currents has ceased to blow, the swells still continue for some time, and even after the swells have ceased to be perceptible the longshore wind current remains quite strong, the momentum which the water acquired during the period of storm not being expended for some time after the storm has ceased. It not infrequently happens that a new wind from a different quarter may spring up and start to generate a current in an opposite direction. This affects the surface water first, while the lower water still retains the motion in the original direction, also the water immediately along the shore is affected to the bottom some time before the deeper water off shore has had its momentum destroyed and its direction of flow changed.

Transportation During Storms by Wave-Generated Longshore Currents.

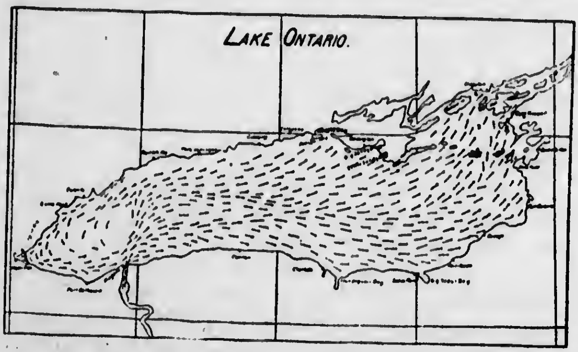
In the shifting of materials along the shores the only effective agents of transportation are the wave-generated longshore currents and the waves associated with them. Transportation of all but the finest materials ceases as soon as the swells disappear, and is at its maximum at the time the waves are largest. The longshore currents of themselves are usually not strong enough to hold even fine sands in suspension for any length of time—as may readily be ascertained by experiment, or as is shown by the rapidity with which the water in the shore zone clears as soon as the waves cease. Clay in suspension is carried for some time by longshore currents, and also by the currents of the general circulation; sands and all coarser materials along the shores cease to move as soon as the agitation caused by the swells stops, they are transported both by waves and currents. The very coarse materials—cobbles and boulders—are shifted almost wholly by the waves.

The Supply of Waste:—Bedrock exposures on the shore of the lake are few in number. For the most part the materials found on the shores and adjacent to them are fine clays and silts, sand and gravels, cobbles and boulders. The clays and silts in large part are derived from similar materials in situ and are brought to the shores by various processes, in small part they are produced at the shore by the grinding of the coarser materials upon one another, and upon bedrock. The sands are derived almost wholly from sands of glacial origin. The gravels and cobbles come from beds of till in large part; along those portions of the shore where there are exposures of bedrock almost all of them are derived from the rock in situ, a small amount of glacial material being mixed with the rest. The boulders and large blocks are usually of glacial origin, though here and there one may note blocks of the adjacent bedrock shifted only a short distance from its source.

Distribution of the Waste on the Shores:—The waste supplied to the shores from the different sources is spread out in a nearly even sheet parallel to the shoreline; much of the finer material is carried out rapidly to the deeper waters and there deposited, while the sands and coarser debris are shifted along the shore within the limits of the wave swept zone.

Most of the active transportation takes place during greater storms; during a period of light winds only sands and fine gravels are moved. Probably the greatest amount of transportation takes place during the period of autumn storms, though a very considerable movement takes place in the spring. During the summer months, except when there occurs an unusually heavy storm, transportation is very slight. During the winter months when the shores become lined with ice, transportation of all materials except sands and silt is at a minimum.

In the shifting of waste along the shore it is being moved locally now in one direction, now in the other, according to the wind direction. It is found, however, that a single great storm will undo the work of many previous gentler winds.



A study of the transportation conditions along the shores of the lake shows that two distinct resultant shifting movements may be recognized. On the north shore it has been found that in the vicinity of Whitby there is a division point west of which the resultant shifting movement is west, and east of which the resultant movement is east. The corresponding nodal point on the south shore lies somewhat west of Charlotte. The general eastward and westward shifting of the shore waste is also shown by the direction of transportation of certain well-known and easily recognized materials, such as fossils from known horizons, and also by the manner in which waste accumulates around docks and other obstructions, whether natural or artificial. It is also well shown by the forms of the various constructional features of the shoreline.

This systematic resultant movement of the waste towards the east and west ends of the lake respectively from distinct nodal zones near the middle of the length of the lake, is seen to be directly associated with the size of the storm waves. In Lake Ontario storms from the southwest will roll waves of maximum size on the northeast shores, the wind and waves having a free sweep toward this section of the shore over the longest part of the lake. Similarly storms from the southeast and east will roll maximum waves toward the northwest shore of the lake. It is these storm waves with the strong longshore currents associated with them that perform the maximum amount of transportation, and are the cause of the resultant shifting movements in the directions indicated.

Not only from actual observation may the waves be seen to be greater at the eastern and western ends of the lake than towards the middle zone at times when storms are blowing toward one end or the other of the lake,but the greater power of these waves is well shown in the height and character of the storm beaches along the shores. Near the middle of the lake on both shores the storm beaches of coarse debris lie about six feet above water level. At the eastern and western ends they lie about fifteen feet above the same level, being a little higher at the east than at the west end. Also at or near the middle of the north and south shores below the storm beaches there is a large accumulation of finer pebbles, gravel, and sand. At the ends of the lake the entire beach is at times made up of very coarse materials, the finer having been rolled out below the calm water level. Wave-base will also lie deeper below the mean level of the lake at the east and west ends than near the middle of the north and south shores.

Character of the Shoreline:—In its initial stages the shoreline of the basin now occupied by the present lake must have been very diverse in character. All later shore processes have tended to smoothen out these initial irregularities producing the long sweeping curves and beaches of graded waste that are its most characteristic feature. In the process of straightening and grading headlands were truncated, lines of sea-cliffs were formed, and bars and barrier beaches were built across many of the originally deep bays.

The barrier beaches which have formed the broad lagoons at the east end of the lake and also at Burlington bay are the most notable of these. Among other shore forms which are characteristic of the present stage of development of the shores of all the lakes is Toronto island, a form technically known as a flying spit.

Toronto Island:—Lake Ontario stood at its present level long enough prior to the formation of Toronto island to cut a sea-cliff along the shore that now forms the mainland adjacent to the harbor. The old beach line can be traced for some distance east of the Don, but opposite the eastern end of Ashbridge's bay, if the old abandoned beach exists, it is not readily distinguishable There is enough of the earlier beach discernible to show that lake Ontario waves were once actively cutting at the Don mouth, from which it is inferred that at that time the Don delta was not encroaching on the lake shore. The formation of Toronto island has been, geologically speaking, recent. Its present location, form and growth are the result of action of several processes whose mode of operation is well understood.

As might easily be inferred, and as has been shown by actual observation in numerous instances, abrupt changes in the trend of the shoreline may frequently cause well defined longshore currents to be carried past the salient and out into deep water, where of necessity they will gradually lose their velocity and discharge the greater portion of their load Raby Head, near Port Darlington, is just such a locality On a number of occasions when strong storms were blowing from the southwest the writer has observed the waters of the longshore current moving eastward along the coast and discharging into the clear waters of the lake off Raby Head. The discolored water, which marked the course of the current, could readily be seen for as much as three miles east of the head, lying probably about two miles off-shore, with clear blue water between it and the mainland.

Coming west from Scarboro along the lake shore, one readily notes that there is a rather obtuse angle between the shoreline in front of the bluffs and that of the old beach back of Ashbridge's bay and Toronto harbor. At Scarboro and Toronto the strongest waves and associated longshore current would come from the east and southwest in former times as now. Because of the marked change in the trend of the coastline, the longshore westbound current would tend to discharge out into the lake at the point where the relatively abrupt change in the direction of the shoreline took place. The cliffs at Scarboro would supply an exceptional amount of loose debris, much more than is found anywhere else along the north shore. The result would be the construction of a flying spit from Scarboro waste reaching out into the lake from the point of discharge of the shore current. This spit would gradually increase in length and also tend to broaden. In time it would protect the land adjacent to the mouth of the Don from eastern storms. Such storms as come from the west would not only be weaker agents of shore processes, but would tend to force the debris which the Don was discharging back into the bay, between the flying spit and the shore. In the early history of the lakes and of the bar it seems probable that the greater portion of the debris from the Don, like that from all the other streams up to the present time, was distributed along the shores by the shore processes, and that no distinctive delta was built up. In later times the protection afforded by the young Scarboro spit guarded the mouth of the Don from master storms, and forthwith it began to build up a delta, and, during the course of delta formation, to aid in filling of what is now called Ashbridge's bay. The westward progress of the spit was, however, far more rapid than the Don filling, so that in time the portion that now forms Toronto harbor was built west of the Don mouth.

At first the flying spit would be narrow and ridge-like, but as the apex advanced into deeper water its progress westward would be slower, giving time and opportunity for storms from other than the dominant direction to variously modify its apex. The general history of all such spits seems to be that when they reach deeper water the outer end shall be turned shoreward by waves and currents from deeper water offshore. The combined action of forward building and shoreward spreading lead, in this as in other cases, to the broadening and hooking of the free end of the spit, and incidentally to the inclosing of a number of lagoons between minor bars built at successive intervals, according as the longshore or transverse processes were more active.

Conclusions:—Toronto island as it stands to-day owes its existence to the inter-relations which have existed between **Shore Processes of Transportation** and the **Supply of Waste.** Interference with either of these will immediately be followed by other changes and modifications on all parts of the island. It is possible to retard the operations of the shore processes, it is possible to reduce the supply of waste—but it is extremely rash to undertake operations of any nature which will tend to destroy the **balance** which has existed between the two, without carefully considering the effects that will necessarily be produced, and taking such precautions as may be needed to insure that these consequent effects shall not be injurious. Put an obstruction across the path of the travelling sheet of waste, anywhere in its course, immediately accumulation will begin east of the obstruction. A diminution of the supply of waste west of the obstruction will immediately be followed by an attack of the erosion processes on those portions of the beach which are robbed of their protective cover of moving waste.

The piers at the Eastern Gap are checking the travel of waste westward. This is shown by the marked accumulations east of the piers. The equally marked recession of the beachline west of the Gap was a necessary result of this stoppage. Were it possible to check completely the westward movement of the shore waste at this point the destruction of all that portion of the island which lies west of the Gap would soon follow. To maintain the present beachlines it will be necessary to adopt measures that will check the operation of the waves and currents of the lake on that portion of the beach which is deprived of its normal supply of waste. The method adopted should be one that has been proven to be efficient under conditions similar to those which will exist along the beach west of the Gap.

With reference to the preservation of Toronto island there is still another consideration, which has, so far as I am aware, never been taken into account. The landholders who own the properties along the shores at Scarboro have been losing thousands if not millions of cubic yards of material annually. To them this has been a direct financial loss, though if they have appreciated it, they certainly have failed to take any efficient steps to curtail the losses. Some day they will wake up to the fact that unless adequate steps are taken to retard the erosion of the cliffs nothing will be left to them. As soon as steps are taken to preserve the cliff fronts at Scarboro the supply of waste which uses Ashbridge's Bay bar as a road by which to reach the dumping-off place at the west end of the Island, will be reduced. With a reduction of the waste supply there will be a readjustment of the shore forms and shorelines. The cutting through of the bar will follow almost immediately, and its destruction will then be a matter of a very short time unless steps are immediately taken to check the action of the waves and currents along the bar in a manner similar to that now required west of the Eastern Gap.

In the second place, and this has a more direct bearing on the problem of sewage disposal and water supply now under consideration; there is indisputable and incontrovertible evidence that the *resultant* movement of all solid materials at the shore zone is westward, no matter what may be the direction of local movements at any given time. This movement is always associated with and accompanies the longshore currents movement, hence there is a master movement of the longshore currents westward. These currents extend out from the shore to beyond wave base.

It is also known, largely from investigations of the United States Weather Bureau, that in the western end of the lake there is a nearly constant movement of the waters as a **backset eddy.** Where the edge of this eddy approaches the north shore near Toronto island and westward, even during the periods when the movement of the surface water along the north shores is eastward, there is every reason to believe that this backset eddy continues on its course.

The local longshore currents westbound off Scarboro sometimes attain a velocity of nearly four miles per hour during a period of strong easterly winds. This means that any waste which would float or mix with the waters of the lake would occasionally reach the western end of the Island within two and a half hours from the time when it was discharged into the lake at any point near Victoria Park.

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