CHAPTER 76

ON THE HYDROGRAPHY OF THE RIVER CLYDE

by

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INTRODUCTION

The River Clyde is one of the major industrial rivers of Scotland and the shipbuilding on the banks of its estuary has been famous for centuries. With the increase in the size of the ships being constructed and using the Clyde as a port, steps must be taken to ensure that the Clyde maintains its relative position. In order to study the effect of various proposals for improvements, a large scale hydraulic model involving the simulation of saline stratification and sediment movement has been commissioned by the Clyde Port Authority and is now being constructed and operated under the direction of Professor Frazer and Dr. Barr of the University of Strathclyde. This paper describes some of the field work carried out in conjunction with this model study in order that water and sediment transport may be correctly simulated.

GEOGRAPHIC DESCRIPTION

The drainage area of the River Clyde and its tributaries (Fig.1) is some 1,500 square miles and in its 95 mile path to the sea, the Clyde flows through the rough moorland of the Southern Uplands, where it rises, into the arable farmland of mid-Lanark, before passing through and being polluted by the heavy industrial areas of the counties of Lanark, Dunbarton and Renfrew. The Clyde Estuary (Fig.2) is taken to begin at the tidal weir in the centre of the City of Glasgow. This underflow weir is used to regulate the upland discharge but is not raised or lowered to any set pattern. In the 22 miles from the tidal weir to where it spills into the Firth of Clyde at the Tail of the Bank, the estuary varies in width from 400 feet at Glasgow Bridge to nearly 2 miles at Greenock. In the upper reaches, the channel is trained extensively on either side by docks, quays and shipbuilding yards. At Bowling, ten miles downstream

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of the weir, the estuary begins to widen out with sand and mud flats on either side of the navigational channel which only requires a single training wall a mile and a half in length, midway between Bowling and Dumbarton. Below Dumbarton the navigable channel moves over to the south bank, to Port Glasgow and Greenock where further docks and shipbuilding yards are situated, before discharging into "The Hole," a 250 foot deep off Greenock. The present navigational channel has gradually evolved from various capital dredging and training schemes carried out during the past 200 years and the depth of water has gradually increased until there is now at least 28 feet at L.W.O.S.T. nearly all the way up to the City of Glasgow. At L.W.O.S.T. most of the banks between Bowling and Greenock would be exposed. Three major tributaries run into the estuary; the Kelvin and the Cart draining the north and south bank respectively, join in the upper reaches while the drainage from Loch Lomond comes in as the River Leven much further downstream at Dumbarton.

At the Tail of the Bank the change in the physical boundary of the estuary is very marked viz. from a drowned river valley to a fiordic loch system. The sea lochs are fairly deep ($>$100 feet) and narrow and some like the Gareloch and Loch Goil exhibit the narrow mouth and shallow sill of the classical fiord. The average depth of the plateau between Gourock and Kilcreggan is about 100 feet, while Loch Long has a depth of around 200-300 feet which decreases to nearly 100 feet at the sill just North of the Cumbraes.

FRESH WATER INFLOW

Table I gives some indication of the relative magnitude of the various sources of fresh water inflow to the estuary. The River Clyde is the major source of fresh water under the tidal weir at the head although the Rivers Kelvin and Cart make a significant contribution. The River Leven carrying the drainage from Loch Lomond into the lower reaches has an average discharge slightly greater than the Clyde although still considerably less than the combined inflow at the head of the estuary. On flood flows however, the storage of Loch Lomond makes the Leven insignificant compared with the flood peaks found on the Clyde and it is these flood peaks which can play a significant part in estuarine hydraulics.

Table I

Daily Flows in Cusecs

	D.W.F.	Normal	Av. Flow	Maximum Daily (3 per annum)
Clyde	285	820	1,368	13,000
Kelvin	50	180	298	2,000
Cart	95	150	206	3,700
Leven	520	1,330	1,398	4,000

TIDES

The tides in the Clyde area are largely semi-diurnal although a diurnal influence of up to 10 percent of the tidal range may be apparent at certain times of year.

Table 2.

Tidal Levels (in feet above O.D. Newlyn)

	High Water		Low Water		Range	
	Springs	Neaps	Springs	Neaps	Springs	Neaps
Cumbraes	+5.9	+4.0	-3.7	-1.8	9.6	5.8
Greenock	+6.0	+4.2	-4.1	-2.0	10.1	6.2
Glasgow	+7.6	+5.1	-5.9	-2.8	13.5	7.9

From Table 2 it can be noted that little change occurs in water levels between the Cumbraes and Greenock, but there is a marked alteration of levels between Greenock and Glasgow with the tidal range increasing by about thirty percent on moving up the channel. There is similarly very little difference in time of High and Low Water between the Cumbraes and Greenock, but from Greenock to Glasgow the time difference varies from 30 minutes to 1 hour's delay of High Water at Glasgow from Neaps to Springs, and from 50 minutes to 1 hour 25 minutes in the delay of Low Water. During Spring tides especially, a slight distortion may be noticed in the trace of the rising tide at the Cumbraes which would have become a significant distortion on the trace at Greenock. In its progress up the channel the tidal curve becomes so altered (Fig. 3) by the effects of these higher harmonies that it has a very marked effect on the currents present in particular their ability to transport sediment. The distortion generally becomes less noticeable as the tides move away from Springs until at Neaps it is generally not detectable.

SALINITY

The salinity in the Outer Firth varies from 32°/oo to 33°/oo, but during heavy rains and high fresh water runoff this may be considerably depressed near the surface and salinities as low as 17°/oo in the channel to the West of the Cumbraes, and 27°/oo in the channel to the East have been noted during extreme conditions. Further inland in the Cloch-Dunoon area there is still this marked throw of fresh water influence to the western bank, and salinities fluctuate considerably with the fresh water runoff but with negligible effect below 30-40 feet - ignoring the seasonal changes in the salinity of coastal waters. The dip of the isosalines to the West is generally measured as about 60 feet over a distance of 1 mile compared with 49 feet calculated from Coriolis Force considerations. Differences in salinity of up to 5°/oo in the upper layers of water is usual and during spates, a surface salinity of 11°/oo has been recorded.

Off Greenock the stratification is more marked and the fresh water from the Clyde lying on the surface during the ebb tide is discharged over the full width between Greenock and Ardmore. At Low Water on the change of the tide, a large proportion of this surface water is swept away by the flowing tide into the Gareloch where it undergoes considerable mixing as it passes through the Narrows. An interesting phenomenon which was recorded on one occasion off Greenock was an apparent upthrust of water from the 200 foot "Hole" into the 30 foot deep navigational channel (Fig.4). At the beginning of the rising tide the 32°/oo isosaline rose out of the "Hole" breaking the water surface and moving into the navigational channel, completely cutting off the water moved down by the ebb tide. If this mechanism were a permanent one, it would have considerable significance in sediment movement and pollution considerations, but two subsequent surveys failed to record the phenomenon.

The physical boundaries of estuary inland from Greenock suggest the coastal plain or drowned river valley estuary as defined by D.W. Pritchard[1] and on investigation of the salinity distribution puts it into the partially stratified category. As could be expected from the relative magnitudes of river inflow and tidal volumes, variations in fresh water inflow has a marked effect on the position of the isosalines and in times of spate will drive the salt water well downstream even near the seabed. (Fig.5). During periods of low river flow there is a tendency for a sharp interface to form at a depth of 10-15 feet for a distance of about 3 to 4 miles in the upper part of the estuary where differences of 5-10°/oo of salinity occur within a few feet of depth. At most points in the navigational channel the difference in salinity between surface and bottom waters tends to increase on the falling tide along with a general decrease in salinity and decrease on the rising tide along with a general rise in salinity. Each of the tributaries has its own "estuary" and despite their significant contribution to the fresh water inflow, rarely depress the longitudinal salinity profile of the main channel. Temperature stratification is seldom found to be of great significance in considering the density structure in the Clyde despite power station operation in the upper reaches.

WATER MOVEMENT

With some density stratification present throughout the area it is not surprising to find that the residual movement throughout the area is a two layered one with the fresh water moving seaward in the upper layer and the salt water penetrating landward along the sea bed. The depth of zero residual movement is greater in the deeper water but is generally around 30-40°/oo of the depth although in particular areas of the outer estuary, the local topography and/ or Coriolis Forces may cause this to be somewhat deeper or shallower. Fig. 6 gives an indication of the general pattern of residual movement found. Each residual movement was obtained from the vector sum of half hourly readings taken over a period of 25 hours at several points on the vertical. For the sake of clarity only some of the positions on the vertical are shown in the figure. In Lower Loch Long between Dunoon and Innellan, the seaward flow is much stronger along the western bank and the upper layer is fairly deep. In the case of the landward flow, the stronger movement is on the east side and here the plane of zero residual movement is comparatively shallow. The currents generally however are relatively weak - less than 1 knot - and are even weaker in Loch Long itself North of the Holy Loch.

On the plateau between Greenock and Kilcreggan there is a fairly strong residual seaward movement in the surface layer right across the estuary. The main landward thrust which takes place near the sea bed is found along the north shore, north of Rosneath Patch, where there is negligible seaward movement at the bottom throughout the 25 hours of the survey. Currents in this area are much stronger reaching a knot or more when the tide is running. In the comparatively shallow water of the Helensburgh banks, there are some very sharp differences in residual movement with depth; the surface water going towards the Gareloch and the lower layers moving towards the inner Clyde Estuary.

It is in this region that arguments start regarding the merits of true depth measurement and these taken at percentage depths. In an area where tidal range is 10 feet and if the water depth at Low Water is only 12 feet, a measurement taken at 6 feet is at 27 percent of the depth at High Water, and yet at 50 percent of the depth at Low Water. In one case, the measurement is likely to be made in the surface layer and in the other in the intermediate or lower layer of water movement. There is also some disagreement among the protagonists of the fixed position method as to whether one should measure distances from the water surface or from the sea bed, and it has been suggested that a combination of both with an overlap in the middle would be suitable. In any event one generally ends up with a number of positions out of the water column altogether at Low Water and to attempt to rationalise the residual flows in the mid depth region is very difficult. This can become very definite in sharply stratified flow when it may be obvious that the falling tide places the measurement into an entirely different body of water. On the Clyde, measurements were always taken at various fixed depths below the surface of the water and at 2 feet above the sea bed. If however the tidal range was more than 20 percent of the depth at Low Water, the readings were interpolated and expressed at percentage depths. In this way it was felt that the advantages of fixed position of measurement was maintained for computation of the volumes of water passing and yet gave the advantage of percentage depth in expressing residual movement.

In the study of water movement in the navigational channel all the analysis was done on the basis of percentage depths but due to the rigours of having to move the survey ship for passing traffic current measurement could only be taken for periods of 12½ hours at one time. Residual movements for four of the hydrographic stations situated along the length of the estuary are shown in Figure 7. In normal conditions of wind and fresh water inflow the position of zero residual movement is generally between 30 and 50 percent of the depth. Appreciable fresh water inflow will of course depress this, especially in the upper reaches of the estuary where a large spate can force salt water downstream, usually resulting in a seaward residual flow at all depths. The form of the residual flow profile varies considerably with tide and density stratification, but no correlation has yet emerged. An attempt is being made to compute the circulation volume of this differential flow system and relate it to river flow in a similar manner to that found on the Tyne[2] where fairly close agreement was found between results obtained from direct current measurement and these computed from the salt balance. One significant feature of the currents in the navigation channel of the Clyde is the initial thrust of the flood tide, and this can be seen very clearly in Fig. 8 where water speed is plotted against time for various depths. The current quickly builds up to 1 to 2 knots then dies away to almost nothing 2-3 hours after Low Water and then continues as a slow steady current. The reason for this can be seen in the distorted tide curve in Fig.3. This surge must play a major part in any bed load movement since in many points of the estuary it is only during this 2 hour period that there is any significant movement at all near the sea bed.

SEDIMENT TRANSPORT

The sediments of the area are in keeping with the general topography and vary from rock and gravel through sand to fine silts and clays. In the deeper parts of the sea lochs the bottom is generally covered with soft silt although there may be patches of clay or rock here and there. The exposed western edge of the banks between Greenock and Helensburgh are covered with finely graded sands covering soft silt to a depth of 10 feet or more. Wave action on the banks throws the material into suspension and the currents carry away the particles depositing each size fraction in turn, as they are moved from the banks into deeper water. In the channel itself the sands penetrate as far up as Bowling although with an increasing silt fraction. After Bowling the bed is classified as silt, although there is still an appreciable sand content in many parts.

For a man-made dredged estuary the Clyde is remarkably stable with almost 90 percent of the dredging having to be done in the landward 4 miles. In the 12 miles from Bowling to Greenock only occasional dredging is required although the sides of the channel through the banks are largely untrained. The dredged spoil is dumped in 200 feet of water at the confluence of the Holy Loch and Loch Long. Sea bed drifters released at this spoil ground were found only in Loch Long and Loch Goil indicating that the major proportion of the spoil is moving straight up the loch. Drifters released at the disused spoil ground on the end of the plateau however were recorded in the Gareloch as well as Loch Long indicating the likelihood of the return of some of the spoil at least. This was substantiated by a study of charts of the Helensburgh and Greenock banks prepared while this spoil ground was still in use, indicating these were building up at a rate of the order of 200,00 cubic yards per annum.

Within the channel itself the suspended solids content is generally very low - less than 50 p.p.m. - and thus indicating residual movements of less than 20 tons of dry weight per tide. A recording silt meter placed on the sea bed coupled with current measurements taken from an instrument situated on the bed, indicated that most of this takes place during the 2 hour's surge on the rising tide. Attempts to measure bed load movement have so far met with little success although undulation on the sandy sea bed between 11 and 14 miles downstream of the tidal weir could indicate sand waves. They are however restricted to this part of the river and their extent varies apparently at random.

ACKNOWLEDGEMENTS

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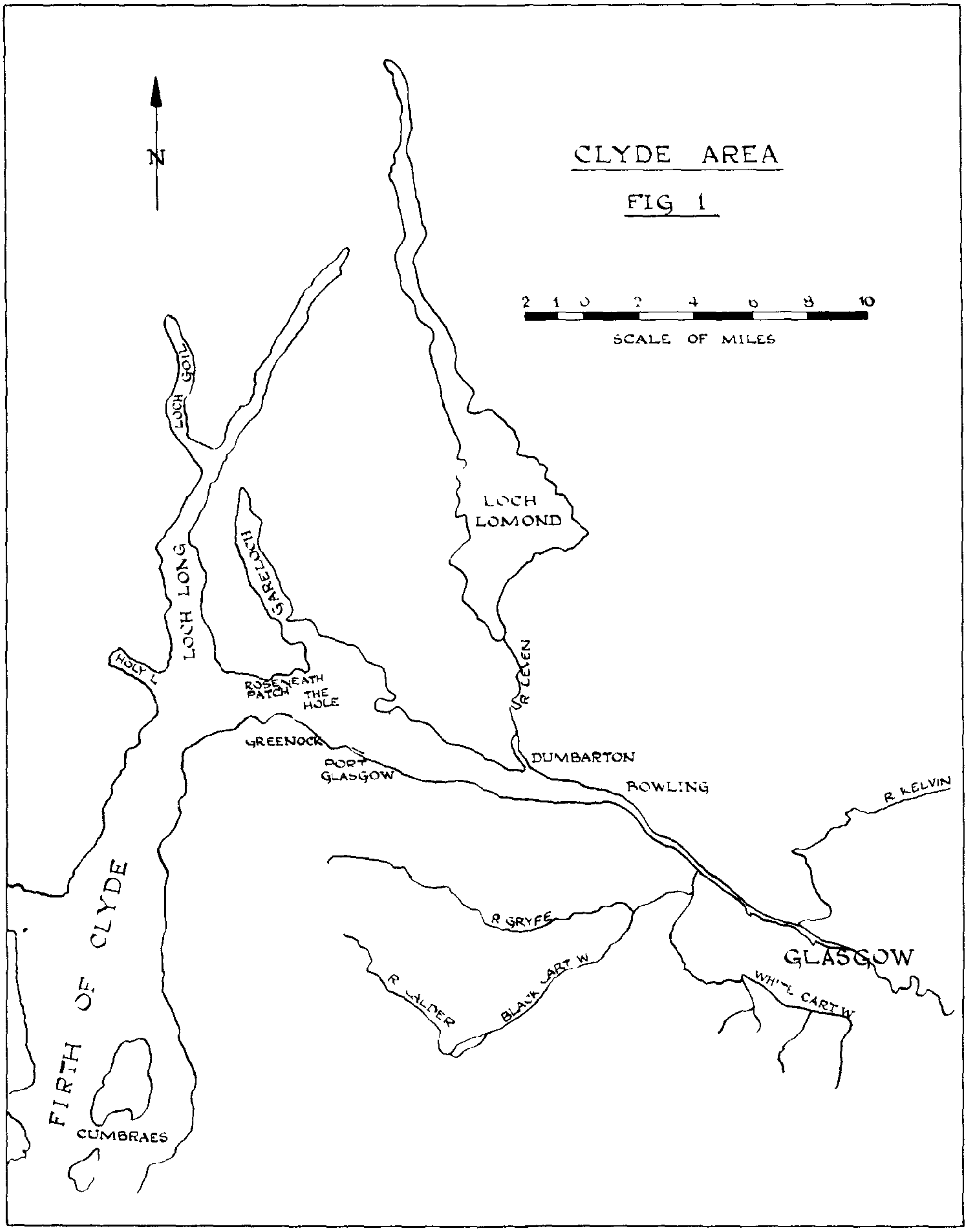
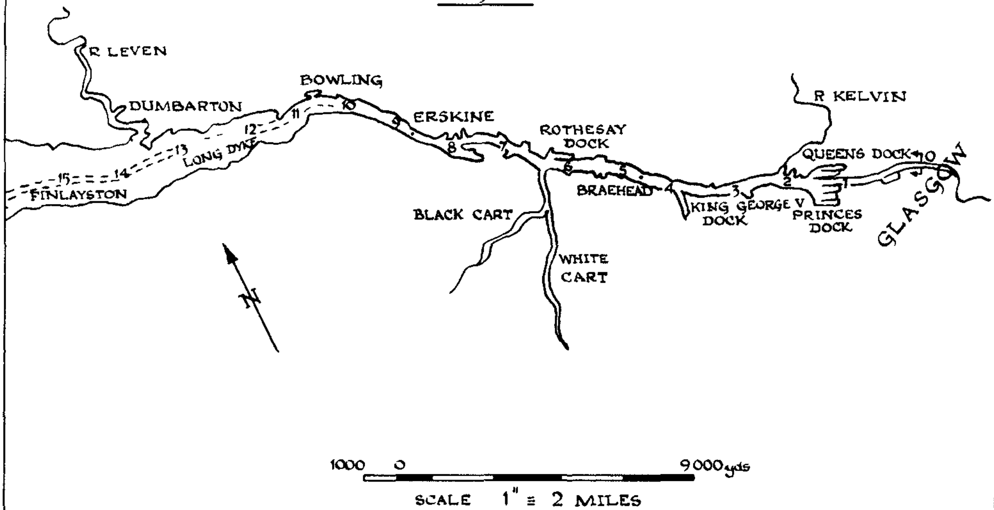
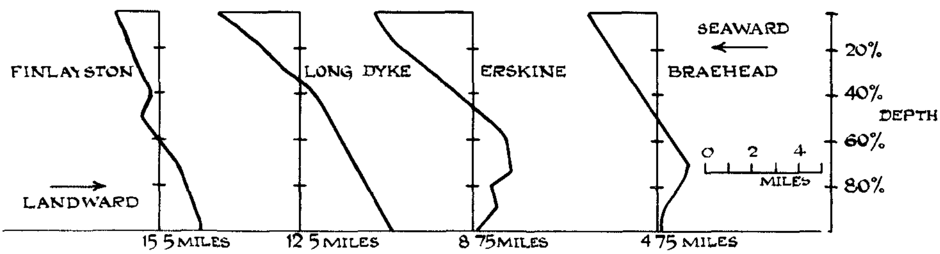

CLYDE AREA
FIG 1
N
2 1 0 2 4 6 8 10
SCALE OF MILES
LOCH GOIL
LOCH LONG
GARELOCH
LOCH LOMOND
HOLY L
ROSENEATH PATCH
THE HOLE
R LEVEN
GREENOCK
PORT GLASGOW
DUMBARTON
BOWLING
R KELVIN
R GRYFE
BLACK CART W
R CALDER
WHITE CART W
GLASGOW
FIRTH OF CLYDE
CUMBRAES

UPPER CLYDE

FIG 2

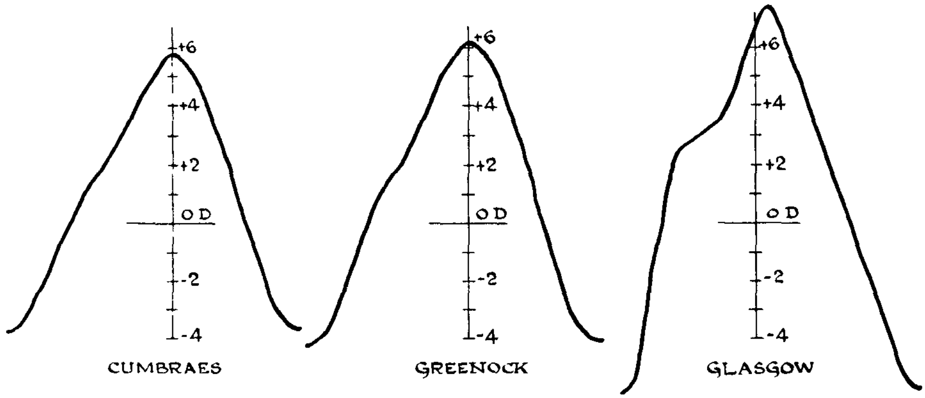




RESIDUAL MOVEMENT

SPRING TIDES

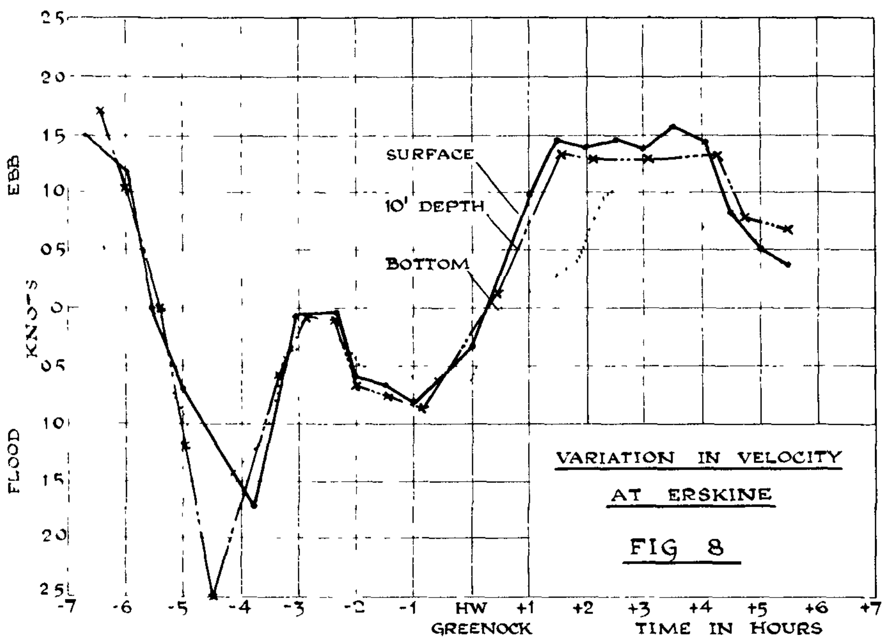
FIG 7



MEAN SPRING TIDE

RIVER CLYDE

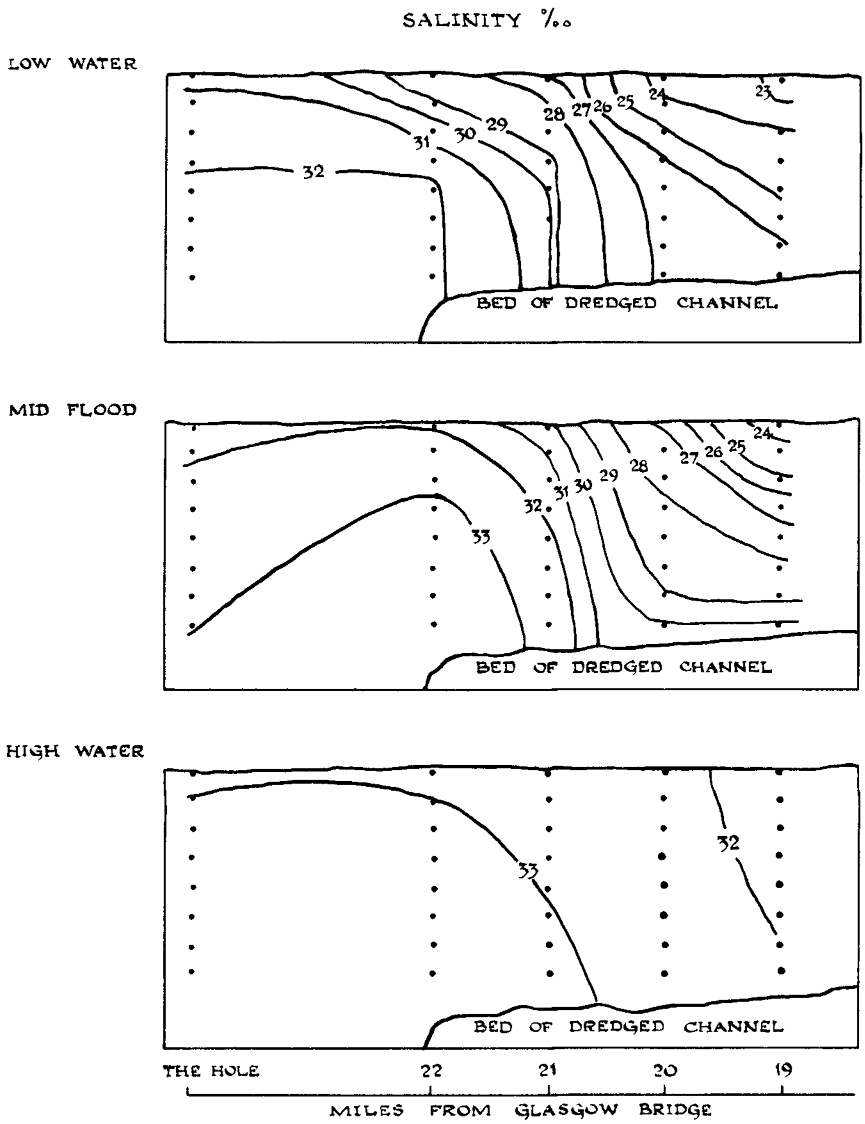
FIG 3



VARIATION IN VELOCITY

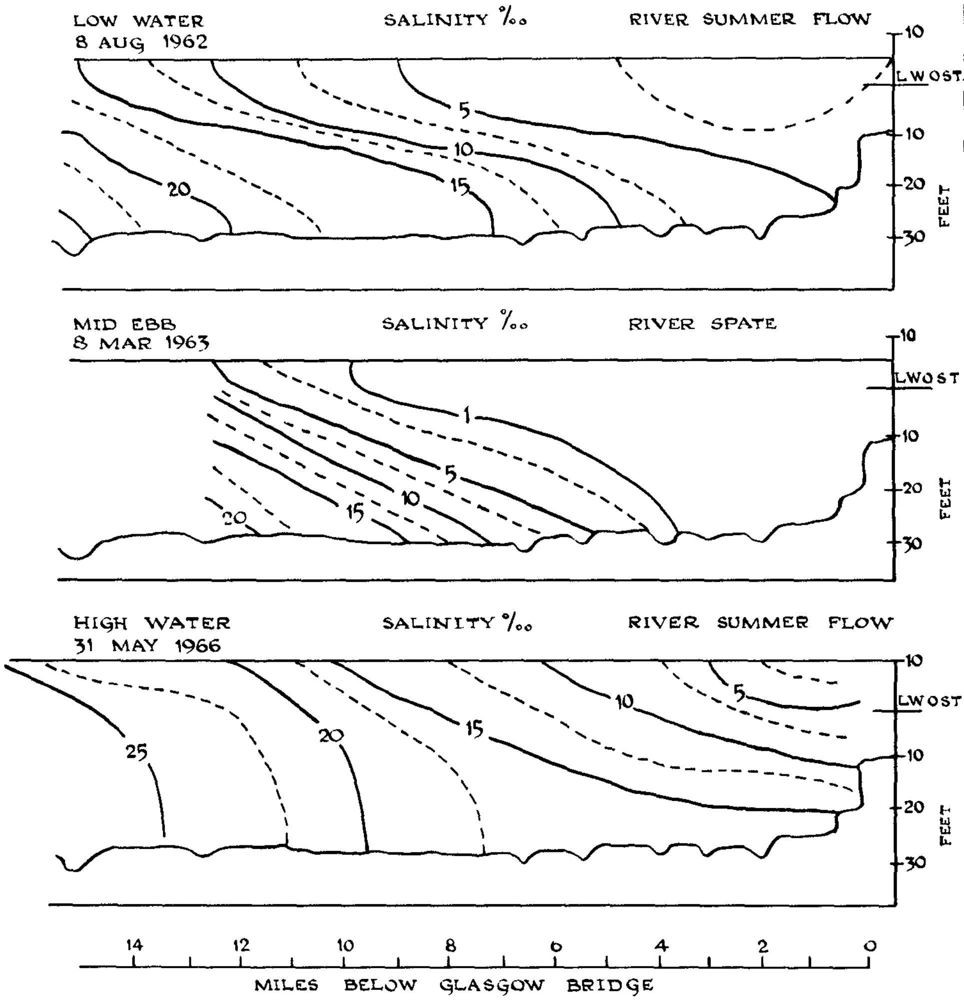
AT ERSKINE

FIG 8



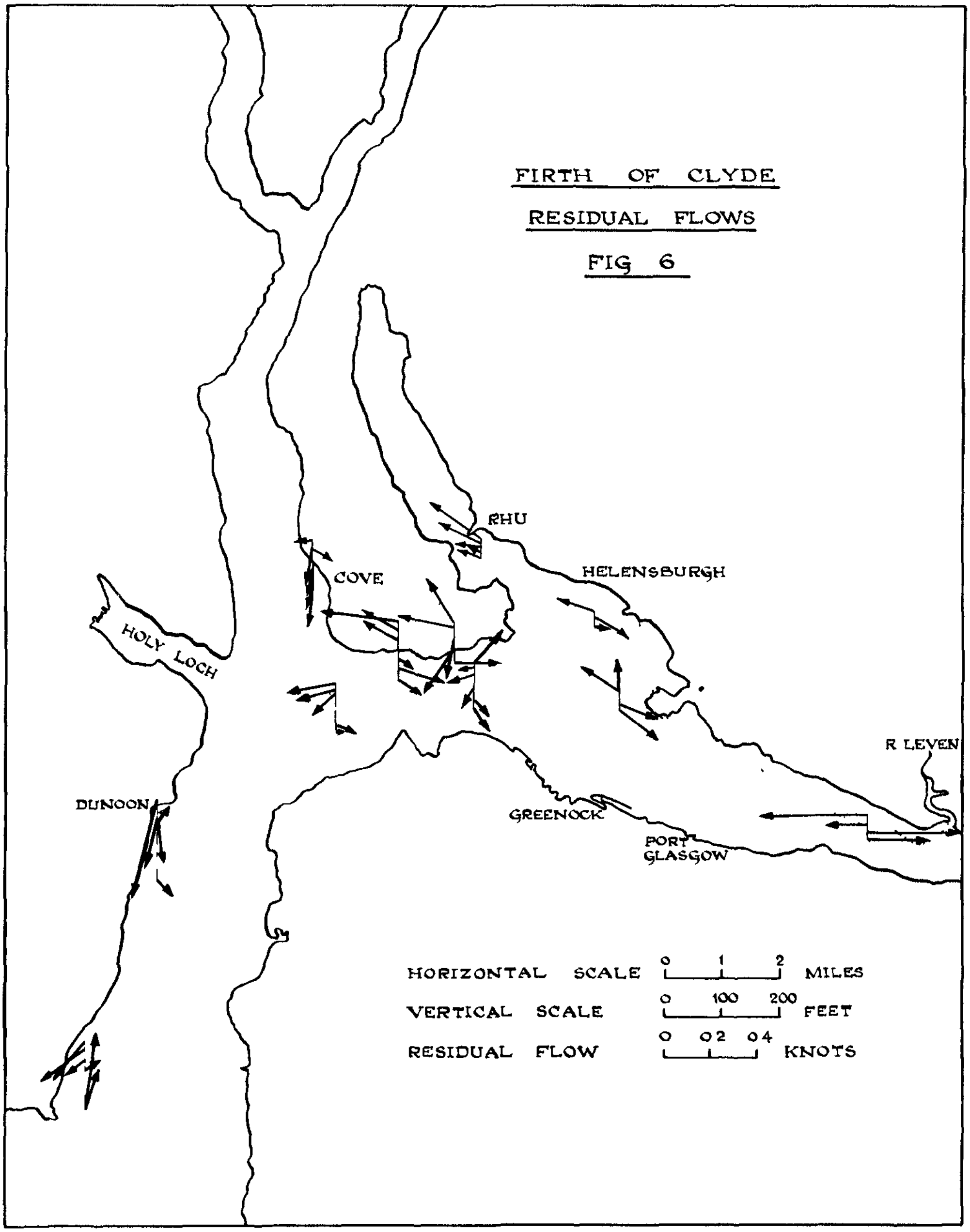
SALINITY TRAVERSE GREENOCK 21 JAN 1964

FIG 4



UPPER CLYDE · SALINITY TRAVERSES

FIG 5


FIRTH OF CLYDE
RESIDUAL FLOWS
FIG 6
RHU
COVE
HELENSBURGH
HOLY LOCH
DUNOON
GREENOCK
PORT GLASGOW
R LEVEN
HORIZONTAL SCALE 0 1 2 MILES
VERTICAL SCALE 0 100 200 FEET
RESIDUAL FLOW 0 02 04 KNOTS