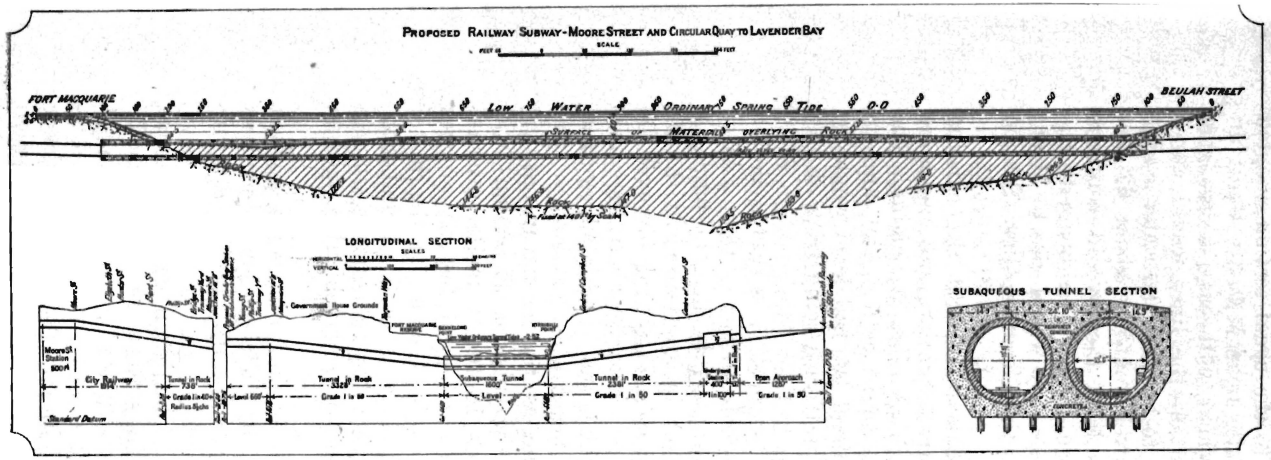

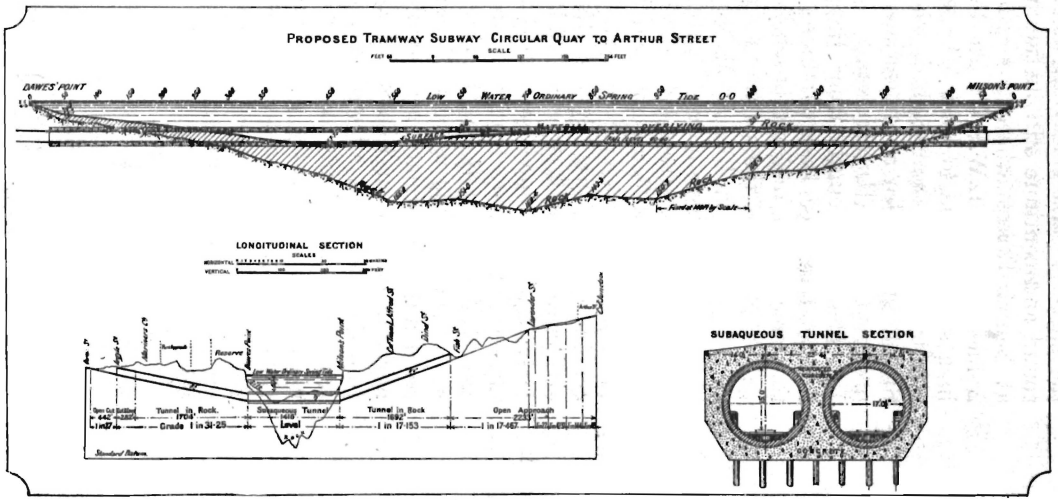

NOTE.—Datum for Borings, Low Water Ord. Spring Tides. Datum for Tunnel (Standard) Mean Sea Level, 2·52 above Low Water.

lines, but falling below these, to between Dind Street and Paul Street. At this point the lines would go into tunnel, which would be in rock, and constructed to the usual section adopted for a double line railway. At a site near Milson's Point an underground station would be provided, with easy access from the surface. After leaving the station the lines would curve round and continue still in tunnel, to beneath the water's edge at Beulah Street, where the rail level would be about 62 feet 2 inches below L.W.S.T. At this level they would continue in a straight line to Fort Macquarie, about in a line with the western wall of the car shed, whence they would rise to Moore Street, giving also a connection to the Circular Quay Station proposed by Mr. Hutchinson.

The total length from the connection with the existing line at Lavender Bay to Moore Street Station, and including the same would, under this scheme, be 2 miles 5¾ chains. The ruling grade on the northern side would be 1 in 50, and on the City side 1 in 40. At Moore Street the rail level would be about 31 feet above mean tide, the platforms being from 35 feet to 48 feet below street level.

The most difficult problem in connection with the design of this scheme was, of course, the subaqueous section. After considering various schemes, the author decided to base his estimates upon the method adopted in connection with the Detroit River Tunnel, referred to above. It should, however, be clearly understood that it is by no means certain that this will be the system of construction which will be adopted, as there are other methods worthy of the closest consideration, so soon as definite information is available as to the nature of the harbour bottom on this line. In the subaqueous section twin tunnels have been allowed for, each 18 feet 6 inches internal diameter, and giving a clear headway of 16 feet 5½ inches above rail, or slightly more than decided upon by the Royal Commission. Owing to the uncertainty as to the foundation, provision has been made for carrying the subaqueous tunnels on piles in this and also the tramway and vehicular subway schemes adopted.

The estimated cost of this scheme, including such portion of the Moore Street Station as will be sufficient for a terminus for the northern suburbs railway system, until the City Railway is constructed, is £753,000 approximately.

Since the report of the Royal Commission on Communication between Sydney and North Sydney was submitted, a scheme for the proposed City Railway was placed before the Royal Commission for the Improvement of the City of Sydney and its Suburbs (1908-9) by Mr. T. R. Johnson, Chief Commissioner of Railways, and was recommended by the latter Commission for adoption. This scheme, though somewhat different to that

proposed by Mr. Hutchinson, provides for a railway connection with North Sydney upon the lines recommended by the former Commission.

PROPOSED TRAMWAY SUBWAY.—The tramway scheme recommended by the Royal Commission provides for connecting on the northern side with the existing tramway at Junction Street, opposite Arthur Street, where the rail level is about 135 feet above H.W.S.T. Thence it would follow down Arthur Street and Brisbane Street, which it is proposed to widen, to Lavender Street, which would be crossed at its present level. After leaving Lavender Street, the line would skirt the cliffs to Dind Street, where it would run into a double line tunnel to Milson's Point between the ferry pontoon and the horse ferry, where the rails would be at about the same level as in the proposed railway subway. From Milson's Point there would be a pair of subaqueous tunnels, each 17 feet 0½ inch clear inside diameter, giving 15 feet headway clear of the rails, and extending to Dawes Point. This portion of the work would be generally similar to that described for the railway subway. From Dawes Point there would be a double line tunnel rising to a point near the Seamen's Home in Lower George Street, whence the lines would be continued in cut and cover to the southern side of Argyle Street, finishing with a loop in the open at Barton Street, near the Harbour Trust building. The total length from the junction with the northern tramway system to Barton Street is 1 mile 37¾ chains.

The steepest grade on the northern side would be 1 in 17.15 and on the city side 1 in 27. The estimated cost of this scheme is £460,000 approximately.

PROPOSED VEHICULAR SUBWAY.—To give a suitable connection with North Sydney for vehicular traffic and foot passengers is the most difficult problem of the three.

The instructions received by the author from the Royal Commission were to provide for a roadway 16 feet wide and small footpaths. This width is similar to that in the Blackwall and Rotherhithe Tunnels under the Thames, London, but the author stated in his evidence that on account of the volume of motor-car and other light traffic that will probably use the tunnel, a width of 16 feet would, in his opinion, cause inconvenience if extending over a long length, and in consequence, though the above dimensions were adopted in the subaqueous section, an increased width was provided for on either side of the water.

On the northern side the route adopted for this scheme is identical with that described for the proposed tramway so far as Dind Street. On this portion, which would be in the open, a roadway 50 feet wide with two 10 feet footpaths, has been allowed for. From Dind Street to the water's edge at Milson's Point the line would be in tunnel, with a roadway 27 feet wide

between kerbs, the footpath width being reduced to 5 feet. The line of the tunnel at Milson's Point would be adjacent to, and on the western side of the proposed tramway subway, and the level of the roadway, would be at about the same level as the rail level in that proposal.

The subaqueous section would follow immediately to the west of the line of the tramway proposal to Dawes Point, with a roadway of 16 feet and two footpaths of 4 feet 6 inches in width. From Dawes Point it would rise in tunnel to connect with the new low level roadway proposed by the Sydney Harbour Trust at Pottinger Street.

The total length from Arthur Street to Pottinger Street is 1 mile 28 chains. The steepest grade on the northern side would be 1 in 17.15, and on the city side 1 in 24. The estimated cost of this scheme, if the tramway subway were constructed first is £502,000; if the vehicular subway were constructed first, £532,000. The difference represents the value of work common to both schemes.

Recommendations of Royal Commission.—The above is a brief description of the subway schemes recommended for adoption by the Royal Commission upon Communication between Sydney and North Sydney, whose conclusions were as under:—

"Having thoroughly weighed the evidence and considered all the circumstances, your Commissioners are of opinion that it is expedient to promptly provide increased and improved facilities of communication for passenger and vehicular traffic between Sydney and the suburbs on the northern side of Sydney Harbour, upon the following grounds:—

"1. Public safety and convenience.

"2. Economy of time.

"3. Minimising the number of steam ferry boats crossing the Harbour from Circular Quay.

"4. Reducing the congestion of ferry traffic there.

"5. Assisting to reduce impediments to shipping passing up and down the fairway of the Harbour.

"The improvement of the means of communication between the present Goods Depot at Darling Harbour and the main northern line, contemplated by the Chief Commissioner for Railways, will meet all the requirements of freight traffic, i.e., ordinary goods traffic.

"The best practical and most economical method of establishing direct communication, which will avoid obstruction to harbour navigation, is by subways. The railway and tramway subways should permit of rolling stock of standard dimensions being used, with electricity as a motive power. Some of the reasons for these conclusions may be enumerated:—

"(1) The fairway of the harbour would not be obstructed in any way by subways, whereas any practicable bridge must have a pier standing in, or projecting into, the harbour.

"(2) The combined capital cost of the necessary subways for all classes of traffic would be considerably less than that of a suitable bridge.

"(3) Railway, tramway, and vehicular subways could be separately undertaken, and completed independently of each other. With a bridge, embracing similar facilities, the whole structure must be completed before any of the respective services would be available.

"(4) Subways would be convenient and comfortable, and enable railway and tramway passengers to reach the different parts of the city with greater ease than by bridge.

"(5) The railway and tramway systems of Sydney and North Sydney can be more satisfactorily connected up for through traffic by subways than by bridge.

"(6) A costly section of the Milson's Point-Hornsby railway between Bay Road Station and Milson's point would be retained as portion of the through line which could not be done with a bridge.

"(7) Increased accommodation, when required, could be provided more economically by additional subways than by bridge.

"Passenger lifts should, on account of the heavy cost of working, be avoided where practicable, by keeping the stations and stopping-places as close as possible to the surface, so that ramps and steps could be used.

"The construction of the vehicular subway should be deferred, and, in the meantime, an improved ferry service promptly provided between Dawes Point and Blue's Point.

"When this improved service is available, the vehicular ferry service between Fort Macquarie and Milson's Point should be closed.

"Before concluding this report, your Commissioners desire to offer some remarks bearing on these recommendations.

"Under ordinary circumstances, the extension of the North Shore railway into the city would probably be first undertaken. This is, however, the most extensive of the works proposed, involving the electrification of that line and the provision of a power-house.

"The tramway subway scheme is not so extensive, as it only requires the provision of the subway and the extension of the existing service into the city, possibly involving the provision of some slight additional power.

"Should it become a question of giving priority to either scheme, it is pointed out that, at the present time, the tramway traffic exceeds that of the railway, and the selection of the tram-

way extension would, therefore, confer a convenience on the greater number, which would contribute in a larger degree to reducing the ferry traffic. Moreover, by making convenient arrangements for the transfer of passengers at Milson's Point from train to tram, and *vice versa,* they could, pending the completion of the railway subway, use the subway trams instead of the ferry steamers.

"In dealing with the various schemes before your Commissioners it was felt that the available information respecting the bottom of the harbour was not sufficient. Prior to steps being taken to carry out any of the subways recommended, it is very desirable that careful surveys be made along the selected subaqueous routes, with the object of obtaining reliable information as to the character and thickness of the strata overlying the rock, and the bearing capacity of the upper layers upon which the subway tubes would have to be laid. Additional bores should be put down, and this work could be, with advantage, supplemented by sinking small cylinders and driving test piles."

The Royal Commission for the Improvement of the City of Sydney and its Suburbs did not take evidence specially upon the North Sydney connection except as associated with the city railway extension. One of this Commission's recommendations was as follows: "We are of opinion that a city railway, with the North Shore connection should be undertaken without delay."

Since the reports of the two Royal Commissions have been presented, instructions have been issued by the Honorable the Premier, Mr. C. G. Wade, through the Honorable the Minister for Public Works, Mr. C. A. Lee, to have a proper investigation made of the material underlying the harbour bottom upon the lines of the subways recommended, and this is at the present time being done by the Sydney Harbour Trust. With this information to hand it will be more competent to decide as to the most suitable method of constructing the subaqueous sections. Some additional survey information on both sides of the Harbour will also be required before the exact location of the subways could be fixed, but it may be taken that with the information obtained by the 1901-3 Advisory Board and the 1908-9 Royal Commission, the preliminary work upon the North Sydney connection has been brought to such a stage that a definite decision could be come to by the Government upon this important matter.

In conclusion, the author desires to express his indebtedness to the Proceedings of the Institution of Civil Engineers, and of the American Society of Civil Engineers, and to the various Engineering Journals, for much of the in-

SUBAQUEOUS TUNNELS.

Name.	Date.	Purpose for which used.	Internal Dimensions.	Length of Subaqueous Portions.	Maximum depth of invert below water.	Minimum Cover over Roof.	Method of Construction.	Reference.
1. Thames Tunnel (Brunel)	1825-42	Originally vehicular, subsequently railway	Two openings each 14ft. wide	—	—	—	By shield 37ft. 6in. wide, 22ft. 3in. deep, 9ft. 0in. long, ex tail plates. Lined with brick.	Weale's Qu'rt'ly of Eng., Vol. 3, 1845, and Vol. 5, 1846.
2. Tower Subway under Thames	1869	Footway	6ft. 7¾in. dia.	1,350ft. total	Not stated	22ft.	By shield. In clay throughout.	Copperthwaite
3. Cleveland Lake	1870	Water Supply	Not stated	Not stated	do.	Not stated	By shield 6ft. 6in. dia. Lined with brickwork. Shield discarded after driving 140 ft., owing to cracking of lining.	do.
4. Severn River ..	1873-86	Railway	Not stated	About 2¼ mls. at high water.	do.	44ft. 9in.	By ordinary headings. Lined with brickwork — strata rock, marl gravel and sand. Great difficulties with water.	"The Severn Tunnel," T. A. Walker, 1888, P.I.C.E., vol. 121
5. Hudson River	1879-1905	Railway	Two tunnels, one 18ft. 1½in. dia., one 15ft. 3in. dia.	Nearly 6,000 ft.	102 ft.	When shield was within 5ft. of river bed a 15ft. blanket of clay was superimposed	By shield through very soft silt. First Company 1879-82. Then operations suspended to 1889 when recommenced and carried on to 1891. Recommenced in 1903 and completed in 1905. Iron lined.	*Eng. Record and Eng. News.*
6. Stockholm ..	1885-6	Not stated	12ft 3in. high 13ft 6in. wide with arched roof and straight sides	Not stated	Not stated	Not stated	Face supported by plates strutted from iron centres on which concrete roof rested. Freezing also used. Material, gravel with water. Very bad.	*Engineer*, Ap. 9th, 1886. Copperthwaite
7. City and South London Railway.	1886-90	Tube railway	Two tunnels each 10ft. 2in. dia. on 1st section, 10ft 6in. dia. on 2nd section.	Subaqueous throughout whole length of 3⅓ miles length under Thames about 890ft.	73 ft. below h.w.	About 20ft. mostly clay (30ft. of water at h.w.)	By shield. Compressed air used for first time in portion at Stockwell, where in open ballast under 35ft. head of water. Through clay, sand and gravel. Iron lined.	P.I.C.E., Vol. 123. Copperthwaite
8. Vyrnwy Aqueduct Tunnel under R. Mersey	1888-92	Water Supply	9ft.	805ft,	54 ft. below h.w.	Not stated	By shield through loose water-bearing strata. Iron lined.	Copperthwaite
9. St. Clair River (Sarnia Tunnel)	1888	Railway	19ft. 10in. dia.	2,300ft. under R. St. Clair	76 ft.	15ft.	By shield through very soft clay with pockets of gravel and sand. Iron lined.	Copperthwaite
10. Glasgow Harbor under R. Clyde	1890-93	Outside tunnels Vehicular. Centre tunnel for foot passengers	Three tunnels 16ft. dia.	415ft.	60ft. at h.w.	15ft.	By shield through clay and sand. Iron lined.	*Engineering*, May, 1895.
11. Glasgow District Subway	1892-5	Railway	Two tunnels 11ft. dia.	Two crossings of Clyde length not stated	55ft. at h.w.	14ft. to 29ft. of open material	By shield. Two crossings of R. Clyde where material was open sand, &c. No blanket of clay could be used on account of navigation, and serious flows occurred in the river section.	Copperthwaite Simpson, "On Tunnelling in Soft Material."
12. Thames, at Kingston	1891	Water Supply	8ft. 4in. dia.	540ft. total	Not stated	Not stated	Driven by Southwark & Vauxhall Water Co. In London clay.	Copperthwaite
13. Blackwall Tunnel under Thames	1891-7	Vehicular 16ft. roadway and two 3ft. footways	24ft. 8in. dia.	1,220ft, under river 3,116ft. driven by shield	80ft. at h.w.	5ft. (in one place crown was above bed of river), clay blanket used 10ft. max. th.	By shield through water-bearing strata. For nearly one-half of river section through open ballast.	P.I.C.E., Vol. 130
14. Syphon de Clichy under R. Seine	1892-4	Sewerage	7ft. 6½in. dia. inside iron	1,522ft. (Probably total)	60ft. at h.w.	29ft. 6in.	By shield. Iron, lined with concrete.	Legouez 'Emploi du Bouchier' Copperthwaite
15. East R. Gas Tunnel, New York	1892-4	Gas	10ft. 2in. dia.	2,516ft. total of which about 1,500ft were under the E. & W. channels of the East R.	127 ft.	41ft.	Principally by shield through hard gneiss and limestone with fissures of decomposed material in direct communication with river.	Boston Soc. C.E. 17th April, 1895. Copperthwaite
16. Melbourne ..	About 1897	Sewerage	11ft.	Not stated	Not stated	Not stated	Various linings used, viz., concrete blocks, timber and cast iron.	*Engineering*, 11th Nov., 1898.
17. Waterloo and City	1894-8	Railway	Two tunnels 12ft 1½in. dia. on straight 12ft. 9in. on curves.	1 mile 46 ch. Total length under Thames abt. 960ft.	63ft. at h.w.	23ft.	By shield for most part (including portion under Thames), in London clay. On one side of river through water-bearing ballast.	P.I.C.E., Vol. 139
18. Syphon de la Concorde, Paris under R. Seine	1895	Sewerage	7ft. 6½in. dia.	780ft.	Not stated	Not stated	By shield similar to Syphon de Clichy.	Copperthwaite
19. River Spree, Berlin	1896-9	Tramway	13ft. 2in. dia.	1,490ft.	do.	Not stated	By hooded shield. Lined with cast iron and concrete.	do.
20. Syphon de l'Oise Paris	1897-8	Sewerage	6ft. 8in. dia.	919ft. driven by shield	43 ft.	Not stated	Outer skin of steel plates lined with concrete 10in. thick.	do.
21. Baker Street and Waterloo, London	1898-1901	Railway	Two tunnels 12ft. 0in. dia.	About 1,030ft.	70ft. at h.w.	15ft.	By shield through London clay, except under Thames where they were in ballast. Iron lined.	P.I.C.E. Vol. 150
22. Greenwich Footway	1899-1901	Footway 8ft. 8⅝in. wide	11ft. 9in. dia.	1,200ft.	68ft. at h.w.	About 12ft. 6in. of sand	By shield through ballast and coarse grey sand.	do.
23. Boston Harbor	1901-3	Railway	20ft 4in. wide 20ft 6in. high	3,500 (of this 1,100ft. under docks)	90ft. at h.w.	18ft.	By roof shield through strong blue clay, boulder clay, sandy and silty clay permeable by water and some coarse sand. Lined with concrete (no cast iron).	Copperthwaite
24. Lea River ..	1901	Sewerage	11ft. 6in. dia.	About 1100ft constructed with shield	Not stated	Not stated	By shield. Cast iron lined with masonry.	do.
25. Chelsea ..	1901	Water Supply	8ft. 4in. dia.	——	do.	Not stated	By shield. Similar to Kingston.	do.
26. Hilsea Creek ..	1903	Water Supply	11ft. 10in. dia.	600ft.	About 60 ft.	Not stated	By shield, mostly through chalk.	do.
27. River Dee, Aberdeen	1904	Sewerage	7ft. 8in. dia.	344ft.	About 50 ft.	About 20ft.	By shield.	do.
28. Rotherhithe, London	1904-8	Vehicular 16ft. roadway and two 4ft. 8½in footways	27ft. 0in. dia.	1,535ft.	About 72 ft.	8ft.	By shield through 3ft. to 5ft. of limestone, with clay and sand over and sand and gravel under.	P.I.C.E. Vol. 175
29. East R., New York, Rapid Transit (Battery)	1903-7	Railway	Two tunnels 15ft. 6in. dia.	4,200ft.	About 94 ft.	9ft.	By shield through a rock bar with sand and silt on either side. Tunnels settled and were reconstructed in part.	*Engineering Record and Engineering News.*
30. East R., Belmont Tunnel	1904-7	Railway	Two tunnels 15ft. 6in. dia.	3,173ft.	102 ft.	23ft.	By shield through rock, hard pan and sand.	do.
31. East R. P.R.R. Tunnels	1903-9	Railway	Four tunnels 19ft. 0in. dia.	3,900ft.	90 ft.	8ft.	By shield through rock, boulders, mud and quicksand. Clay blanket used.	do.
32. Hudson R., P.R.R. Tunnels	1903-9	Railway	Two tunnels 19ft. 0in. dia.	5,947ft.	90 ft.	About 25ft.	By shield through rock, boulders, quicksand and silt.	do.
33. Harlem R., New York Rapid Transit	1904	Railway	Twin Cast-iron cased with concrete	450ft.	46 ft.	Not stated	By roofed coffer dam under compressed air. Bed of river, soft mud overlying clay and quicksand.	do.
34. Seine Tunnel of Paris, Metropolitan R.R.	1906-8	Railway	Double line	386ft. for large crossing 123ft. for smaller crossing.	36·6 ft.	Not stated	By steel caissons sunk under compressed air through hard material.	Le Genie Civil.
35. Detroit River, Michigan, U.S.A.	1904-9	Railway	Two tunnels 20ft. dia.	2,622ft. 6in.	68ft.	Not stated	Through soft blue clay by steel tubes floated out, sunk and cased in concrete, with reinforced concrete lining.	*Engineering Record and Engineering News.*
36. Gowanus Canal, Brooklyn	1908	Flushing Canal	12ft.	6,270ft.	18 ft. 6 in.	Not stated	By shield through sand to carry water to flush canal.	*Engineering Record.*

formation contained in this paper. He also wishes to thank Professor Warren for the loan of lantern slides of some of the bridges shewn, and to Mr. W. J. Hanna, Under Secretary for Public Works, in accordance with whose permission the balance of the lantern slides have been prepared by Mr. J. Degotardi, of the Public Works Department.

APPENDIX No. 1.

(See attached Table).

APPENDIX No. 2.

PARTICULARS OF POPULATION AND TRAFFIC OF NORTHERN SUBURBS.

The following particulars have been taken from the Report of the Royal Commission on Communication between Sydney and North Sydney. The returns are for 1907, these being the latest available when the Commission presented their Report in March, 1909

	1901.	1907.	Increase.
Population resident in the Municipalities of North Sydney, Mosman, Willoughby, Lane Cove, and Shire of Kuring-gai	40,162	64,610	24,448 = 60·9 p.c.
Railway passengers to and from Milson's Point	2,198,182	4,375,287	2,177,105
Tramway passengers, Northern Suburban Lines	6,420,420	10,082,128	3,661,708
	8,618,602	14,457,415	5,838,813

The railway traffic practically doubled, and the tramway traffic increased 57 per cent. in six years.

Allowing for an annual increase of 6 per cent., the population of the Northern Suburbs within the above areas will be 207,200 in 1927.

The vehicles carried by the Horse Ferry from Fort Macquarie to Milson's Point are about 270,000 per annum, and between Dawes Point and Blues Point, about 160,000 per annum.