Water Quality Functioning of the Mersey Basin, England: Historic Perspectives

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Abstract: The water quality functioning of UK rivers depends not only upon the current state of affairs, but also upon their history. The legacy of an urban and industrial past determines to a major degree, even now, the water quality status of such rivers. Changing water quality cannot be easily viewed without referring to and modelling the ever-evolving industrial, economic and social base. As such it is important to examine the impacts on water quality of the Industrial Revolution through to the present day. Britain was the first to experience the Industrial Revolution. The North West, and particularly the Mersey Basin, led the rest of the world with respect to industrial growth. Anecdotal evidence suggests that the water quality was relatively clean before the start of the Industrial Revolution. The development of the cotton and chemical industries from 1870 onwards increased the pollution load to rivers resulting in a decline in river ecology. Industrial prosperity led to a rapid population increase, and an increase in domestic effluent. As industry intensified during the nineteenth century, the mix of pollutants grew more complex. Direct monitoring of the water quality within the Mersey Basin began only 30 – 40 years ago when environmental agencies were established. Determining the quality of the water, and consequently ecology, prior to this is assessed qualitatively from an anecdotal perspective and quantitatively with simulations using dynamic models. The rivers of the Mersey Basin were affected over time by effluent discharges, abstractions, climatic variability, rapid population growth, industrial growth and the changing efficiency and development of sewage treatment.

Keywords: Mersey Basin; Industrial Revolution; Water Quality; Pollutants

1. INTRODUCTION

The freshwaters of the Mersey Basin have long been used as the area's principal disposal route for mankind's waste. Since the onset of the Industrial Revolution at the start of the eighteenth century the mix and complexity of pollutants entering the system has increased dramatically. The Industrial Revolution did not signify the start of the pollution of the Mersey Basin, more the intensification of the pollution of the basin. As cotton manufacture became established within the area the population grew. Gradually other industries became established in the Mersey Basin. As industry prospered and the population increased there was an increase in both domestic effluent and trade wastes being discharged into the rivers. The water quality deteriorated and became so bad that by the 1950's many of the areas freshwaters were devoid of oxygen [Jones, 2000].

Since direct monitoring of the water quality began only 30-40 years ago when environmental agencies were established, the exact nature of the water quality proceeding, during and since the Industrial Revolution is unknown. Determining the water quality prior to this monitoring is reliant on qualitative assessment from an anecdotal perspective, and quantitatively with assessments of population and economic change. This can be used to gauge how pollution inputs have varied over time.

2. DATA COLLECTION

The purpose of this paper is to ascertain the probable changes in water quality immediately prior to, since and during the Industrial Revolution. Four determinands have been identified which would have affected the water quality of the rivers. These are:

- Flow,
- Population growth,

- Industrial Growth, and
- Sewage Treatment Development.

2.1 Flow and abstraction

The extent to which a pollutant affects a river system is partially dependent on a river's flow rate. River gauging stations have only been present in the Mersey Basin since the late 1930s. These indicate the flow in the river but since information on flow is not available prior to the 1930s, precipitation and abstraction data have been used to indicate changes in historical flow.

Precipitation data for the Mersey Basin for much of the period since the Industrial Revolution until relatively recently is scarce. Meteorological Office data date back to 1772 for a site in Liverpool. Unfortunately from 1805 to 1829, no precipitation records are available for Liverpool, and this gap in data has had to be filled with records from a site in Manchester.

The Water Resources Act of 1963 introduced the system of abstraction licences. Little information on abstractions is available for dates prior to this. Although there are no data on abstraction levels in the Mersey Basin at the start of the Industrial Revolution abstraction did take place. Using knowledge of the expansion of industry in the area since the 1750s abstraction levels have been estimated.

2.2 Population

A direct result of an increase in population is an increase in domestic effluent entering the rivers. Census records have been used to provide an accurate account of population changes in the Mersey Basin since 1801. The increase in population from 1750 – 1801 is based upon estimations formulated in a study by Lawton [1962]. These population changes have been linked to sewage production per head, per day to assess the potential impact on the river systems.

2.3 Industrial Growth

In the absence of historical industrial effluent discharge data for the majority of the period from 1750 the effects of trade wastes on surface water quality have been predicted by formulation of a manufacturing index. The index is based upon production output data, which is available since 1930. Prior to 1930, production output data has been estimated based upon the trend of manufacturing employment figures, also collected from the census. These data are available from 1841, which is when this index is first introduced to the WPI.

2.4 Sewage

An extensive literature review was undertaken to determine the improvements to sewage treatment provision and domestic sewage effluent standards since the 1750s. Improvements that have occurred in sewage treatment have been related to Biochemical Oxygen Demand (BOD) and suspended solid reductions expected by the level of treatment, to enable the improvements to be quantified.

2.5 Compilation of Water Pollution Index (WPI)

As the Mersey and Weaver River Authority stated with regards to the pollution of the river "it should be noted that this problem is intimately interwoven with the matters of industrial direct abstraction, the increasing quantities of the public water supply and resulting increasing quantities of trade effluents" [Mersey and Weaver River Authority, 1969, p74]. The abstraction, population, sewage development data and industrial growth data have been compiled to produce a single Water Pollution Index. An index can be defined as:

"A form of average derived by relating a group of variables to a common scale and combining them into a single number. The group should contain the most significant parameters of the data set, so that the index can describe the overall position and reflects change in a representative manner" [Scottish Development Department, 1976].

The data collected for each of the four determinands has first been transformed to an index of its own. A scale of 1 – 100 was selected for these indexes with a score of 1 reflecting little pollution potential and a score of 100 indicating the maximum pollution potential in the timescale analysed. The four indexes were then compiled to produce the Water Pollution Index.

Each of the determinands of population, abstraction, industrial growth and sewage treatment development were given equal weighting. Abstraction data was used to indicate alterations in flow rate and thus dispersal potential. Precipitation data was excluded from the index since the required weighting was considered too low to be included. However, the relevance of precipitation data to the WPI is discussed later.

3. RESULTS AND DISCUSSION

3.1 Flow and abstraction

The river gauging stations that have been in place since the late 1930's or later provide an insight to the annual flow regime of the rivers. The highest recorded flow at many of the Mersey Basin river gauging stations are in winter, whilst the lowest recorded flows are found in the summer months. This matches the precipitation data shown in Figure 1.

The Mersey Basin experiences mild and wet winters, dry springs, warm summers and wet autumns. The greater level of precipitation in winter causes the higher winter flow rates, and hence greater dilution effect (Figure 1).

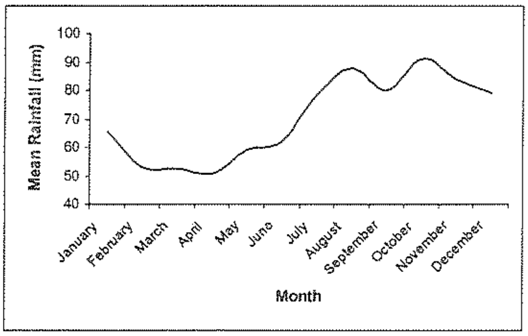

Figure 1. Mean monthly rainfall in the Mersey Basin (1772 – 1998).

Figure 2 indicates annual precipitation since 1772. The dry and wet years show the dispersal potential of the rivers.

Some relatively recent data is available since the introduction of the Water Resources Act. This shows that the major demand for water abstraction is by industry. In 1967 industrial direct abstractions accounted for 6,632 ML/d or 86% of total licensed abstraction quantity in the Mersey and Weaver River Authority. Eighty seven percent of the water licensed for industrial abstraction was for through cooling. Of the remaining abstractions for direct industrial use, 88 ML/d was removed for evaporative cooling and 768 ML/d for general manufacturing [Mersey and Weaver River Authority, 1969]. If industry also has been the major reason for water abstraction historically, the following anecdotal information has been used to estimate past abstraction levels (Figure 3).

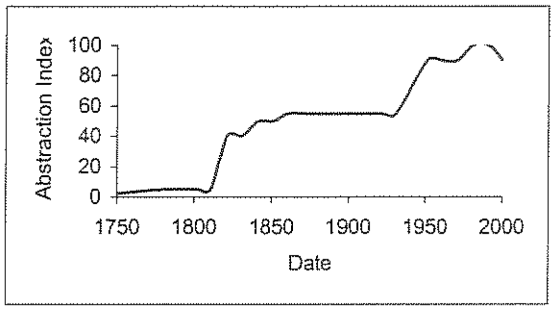

Figure 3. Estimated changes in abstraction levels since 1750 (100 = maximum abstraction).

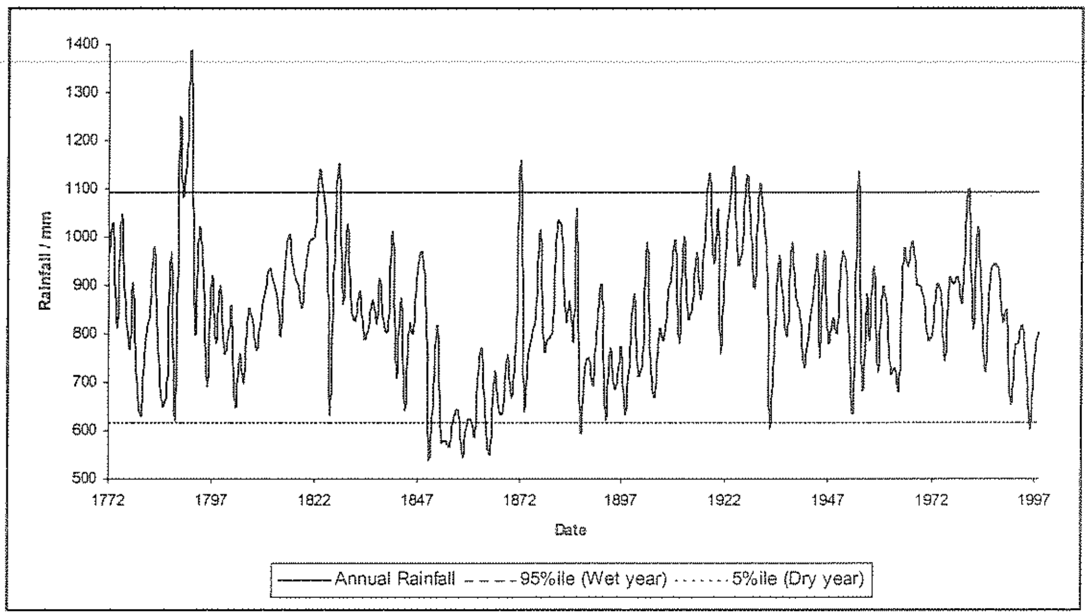

Figure 2. Annual Rainfall at a site in the Mersey Basin since 1772.

From the 1770s the Cotton Industry began to establish itself in the Mersey Basin. Mills were powered by water and this water was abstracted from the rivers before being returned unpolluted. As the industry became more prosperous, more mills became established and the amount of water abstracted from rivers would have grown. The invention of Boulton and Watts steam engine in 1781 increased the number of factories that could be placed in a certain locality. Water was required for use in steam engines. Abstraction levels are therefore likely to have increased. The nature of steam production would also suggest diminished levels of water were returned to the river.

The chemical industry would have further enlarged abstraction levels. The Leblanc industry required water for the production of soda from black ash, and hydrochloric acid from hydrogen chloride. Since the Mersey Basin was a focal point for this industry between the 1820s and 1880s, the rivers would have been affected by abstraction for it. In 1836, hydrogen chloride gas started to be converted to hydrochloric acid with water. This again may have increased abstraction levels, especially with the passing of the Alkali Works Act in 1863, which required that all alkali factories condense at least 95% of the hydrogen chloride gas to hydrochloric acid [Jarvis and Reed, 1999].

During the 1960s, there was increase in demand for surface water abstraction low down in the river basins. Cooling water in particular had begun to reach capacity in sub-catchments such as the lower Manchester Ship Canal and lower River Weaver.

In Mid Cheshire, there has been an increase in surface water abstractions for use by the chemical industry. In 1969 it was predicted that these abstractions would, within the following few years, approach the limit of available resources [Mersey and Weaver River Authority, 1969].

3.2 Population

Urban population growth accompanied the Industrial Revolution. An increase in population results in an increase in domestic effluent. From data compiled of sewage treated at 112 representative works in Great Britain it seems that the average volume of sewage treated daily was 37 gallons per head, per day in dry weather. This value is based on pre war data and it includes both domestic sewage and industrial sewage [Southgate, 1948]. Domestic sewage alone was thought to equal 30 gallons per head, per day in Britain. Figures taken from Davyhulme, one of the main Sewage Treatment Works in the Mersey Basin indicates domestic sewage production to be approximately 36 gallons per day [Klein, 1966]. Overtime the water consumption of the population has increased (improvements in personal cleanliness). Consequently the quantity of sewage production per head, per day would have increased. The historical population of the Mersey Basin has been extracted from census records, and used to indicate the quantity of sewage produced and consequently the effluent that would be received by rivers (Figure 4).

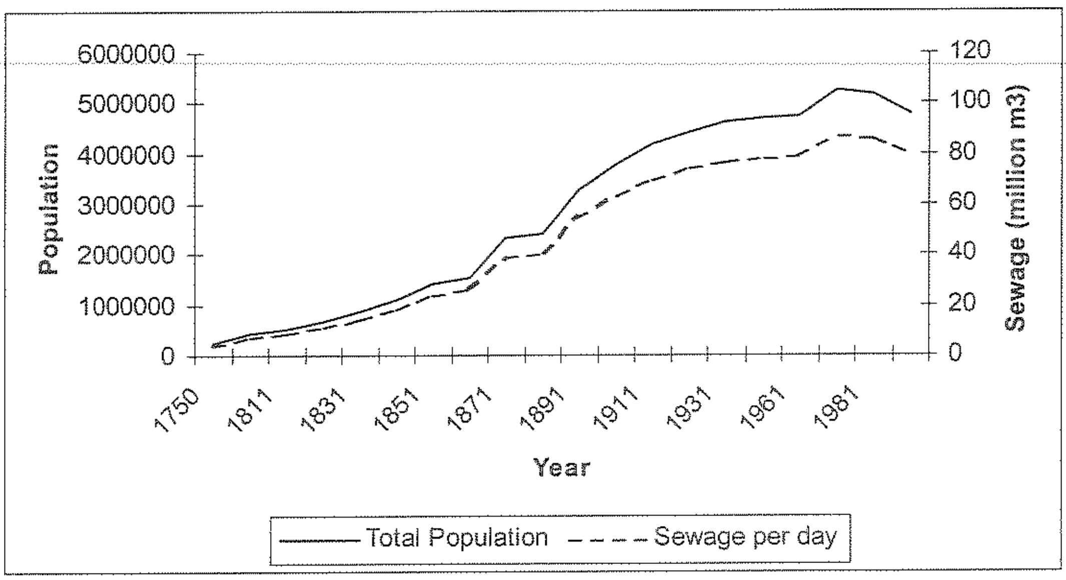

Figure 4. Population and average sewage production per day in the Mersey Basin.

3.3 Sewage

Before 1894, there was no sewage treatment available in the Mersey Basin. As long ago as the sixteenth century privies were built directly over watercourses so that sewage could be carried away. By 1802, some sewers were present within Liverpool and Manchester [Flinn, 1965]. From 1847 to 1858, 80 miles of sewers were constructed in Liverpool with 66 miles of main drains. By 1868, 20 miles of sewers covered Manchester [Redford and Stafford Russell 1940a]. These early sewers merely increased the ease of waste disposal into rivers. In 1848, the Borough Engineer for Liverpool concluded that "The whole of the sewage is still thrown into the river, much of it, indeed into the basins, and all of it at such points as to act prejudically on the health of the town" [cited in Jones 2000, p124].

In 1894, sewage was first diverted to Davyhume and the sewage problem was eased. Table 1 shows the improvements and consequential improvements in sewage effluent quality being released into the rivers. The improvement of legislation has lead to further improvements, such as the recent introduction of tertiary treatment. These have been included in the final index.

Table 1. Improvements to sewage effluent entering the Mersey Basin [based on Redford and Stafford Russell, 1940b].

Date	Improvement	Average reduction in BOD and SS from raw sewage (%).
1894	Davyhulme commissioned	46.25
1905	Bacterial processes introduced	73.75
1935	Activated Sludge Treatment plant	87.5

3.4 Trade Wastes

The manufacturing index (Figure 5) has been compiled to represent the probable production of sewage effluent.

4. THE THEORETICAL MODEL

Compilation of the abstraction, population, manufacturing and sewage data has produced the following Water Pollution Index (WPI) (Figure 6).

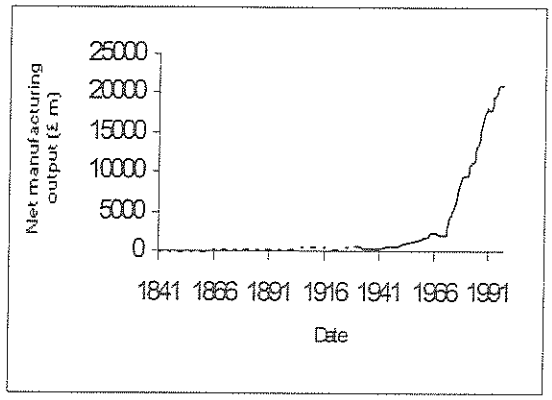

Figure 5. Manufacturing Index developed for the Mersey Basin .

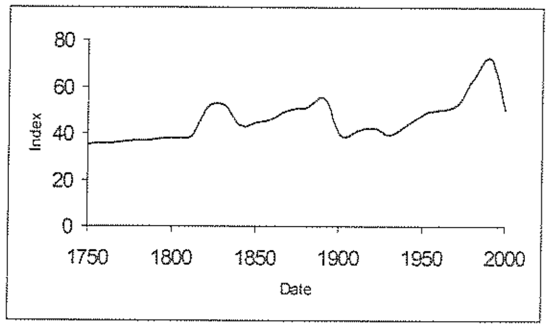

Figure 6. Model of water pollution index, (where 100 = worst quality).

The WPI extrapolated from this data largely follows the trend expected. The WPI in 1750 is 35.4 and is lower than at any other point in the following 250 years. This indicates that water quality has not yet returned to pre-industrial revolution levels. The start of the Industrial Revolution has increased the WPI. Although this rise is slow at first the index increases from 38.3 in 1811, to 50.83 in 1821. This fits the growth of the chemical industry within the area.

The small apparent improvement in the WPI in 1841 is unexpected and does not match the evidence provided by anecdotal data. This anomaly appears to be due to the inclusion of the manufacturing index for the first time. Lack of historical records preceding the 1841 census results in the absence of the manufacturing index prior to this. Anecdotal evidence indicates that the WPI should carry on rising post 1841. The index continues to rise after the initial decline.

The introduction of the sewage treatment works in 1894 causes the next decline in the WPI. As the population and manufacturing output continue to increase the index rises as a greater level of pollution enters the river systems. From 1951 to

1961, the WPI ranges from 48.79 to 50.14. This would be expected to be the maximum level of pollution. At this point, the model suffers its first serious downfall, since pollution levels should decrease after this point. An examination of the model indicates that the manufacturing index is causing this anomaly.

Water quality is likely to have deteriorated in a step pattern. As improvements are made in technology the rate of water quality deterioration would have probably slowed. As the next industrial advance became established, the water quality would deteriorate more rapidly once again, until further technological advances were made to slow this decline.

There would also be annual variations in water quality influenced by factors such as precipitation. In 'dry' periods such as 1853 to 1855 the lesser volume of water for dilution is likely to have detrimentally affected the quality of the river. Wetter years (i.e. 1918, 1924, 1927, and 1930) may provide a temporary improvement in river water quality.

In the year 2000, an accurate improvement in water quality is noted. This was caused by recent improvements in sewage treatment, and reflects the current work by North West water.

5. CONCLUSION

In the absence of historical water quality data a WPI has been developed based entirely on census and anecdotal information. A number of anomalies exist in the model. These have been identified, and with further work on these determinands the potential of the model to represent trends in historical water pollution is apparent. The production of an index has allowed a numeric value to be applied to the trend making it easier to compare one time period with another. It is possible at each time period to determine the major determinand responsible for deterioration.

A number of improvements could be made to the model presented here. A more accurate water pollution index could be calculated by improving the indexes of the abstraction, and effluent quality data, by relying less on qualitative data.

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