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# Groundwater support of stream flows in the Cambridge area, UK

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ABSTRACT This paper describes a feasibility study for the maintenance of stream flows during dry summer months in an area of Cambridgeshire. Groundwater pumped from boreholes is used for augmentation. A mathematical model was used to represent the study area and led to an improved understanding of the aquifer flow mechanisms. Groundwater flow within horizons of high hydraulic conductivity is controlled by rapidly fluctuating head gradients. The model was subsequently used to aid the design of a river support scheme.

## INTRODUCTION

Low stream and river flows frequently occur in dry summers due to low groundwater heads. The situation is likely to be aggravated if water is pumped from an aquifer for public supply. In countries where most rivers are perennial the effects of over-abstraction are causing increased concern. Various attempts have been made to alleviate these low flows; techniques that have been adopted include lining the beds of rivers and supporting the rivers by abstracting water for river support from the aquifer at some distance from the river. This paper will focus on river support from groundwater.

A number of schemes in which rivers are supported by pumped groundwater have been developed in Britain (Downing et al; 1981, Headworth et al; 1983). Certain of the schemes are situated in Sandstone aquifers; due to the significant saturated depth of the aquifer, pumped yields can usually be maintained during periods of low river flows. However the majority of the schemes are in Chalk aquifers and, during periods of low river flows, the groundwater heads and also transmissivities are low with the result that it may be difficult to maintain the required output from the pumped boreholes (Rushton et al; 1989).

The Chalk north-east of Cambridge is a major source of water for public supply. For several years there has been concern about the effect of the abstractions on rivers and watercourses. Groundwater fed streams and springs are valued features of the landscape and there are several important wetland conservation areas.

It is the responsibility of the National Rivers Authority (NRA) to protect the aquatic environment whilst allowing water resources to be utilized effectively. In the study area these two objectives appear to be in conflict. However, this paper shows that by maintaining stream flows using abstracted groundwater, it is possible to enhance the water environment whilst increasing abstraction for water supply.

A feasibility study is described which led to the decision to proceed with a river support scheme. The study involved extensive field work and the development of a mathematical model. The mathematical model was subsequently used to evaluate the feasibility and relative merits of different options.

## THE STUDY AREA

The study area covers some 600 $km^2$ to the north east of Cambridge in Eastern England. Important features are shown in Fig.1. The area lies on the Chalk outcrop, which is the principal aquifer in this region. The Chalk dips to the south-east whilst the predominant topographical gradient is to the north-west (Fig.2). It is an area of gentle relief, ranging between 5 and 115 m above ordnance datum. With an annual rainfall total of only 570 mm and actual evapo-transpiration of 430 mm this is one of the driest areas in the country.

Prior to the development of the river support scheme, licensed groundwater abstractions for public supply totalled 73 Ml $day^{-1}$. Groundwater abstraction for other purposes is negligible.

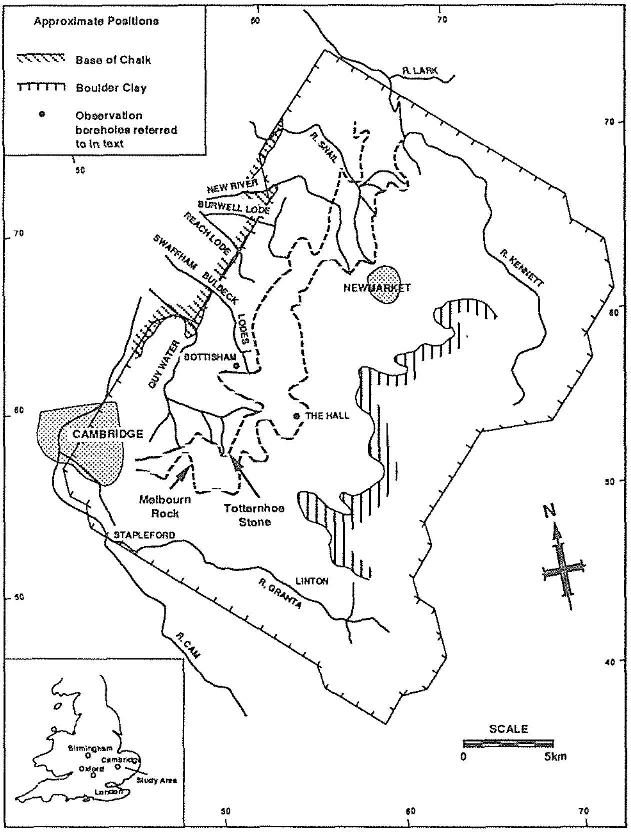


FIG. 1 Lodes-Granta Area.

### The surface water courses

The River Granta to the south-west and the River Kennett to the north-east are important in terms of groundwater resources and were an integral part of the modelling study, but they will not be discussed further in this paper. In between these two catchments there are numerous spring-fed streams which drain to lowland canalized rivers (known as Lodes). The main issue of this study is the significant fall in the flow of these streams during dry periods.

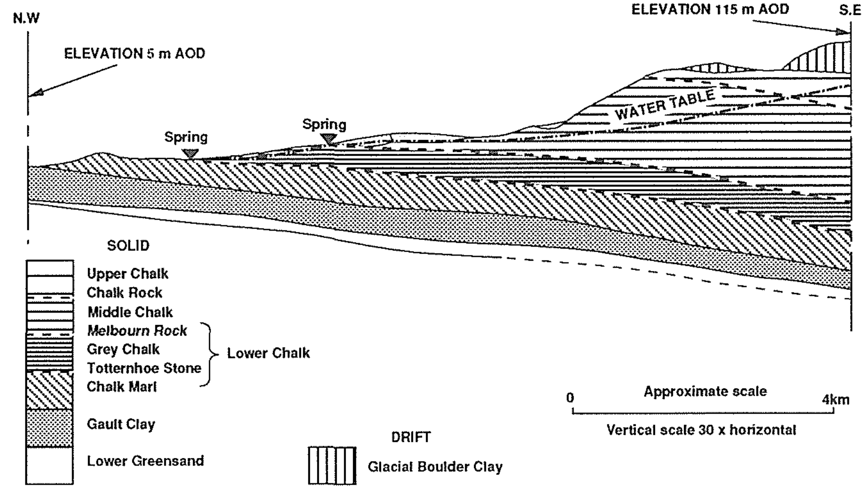


FIG. 2 Representative cross section.

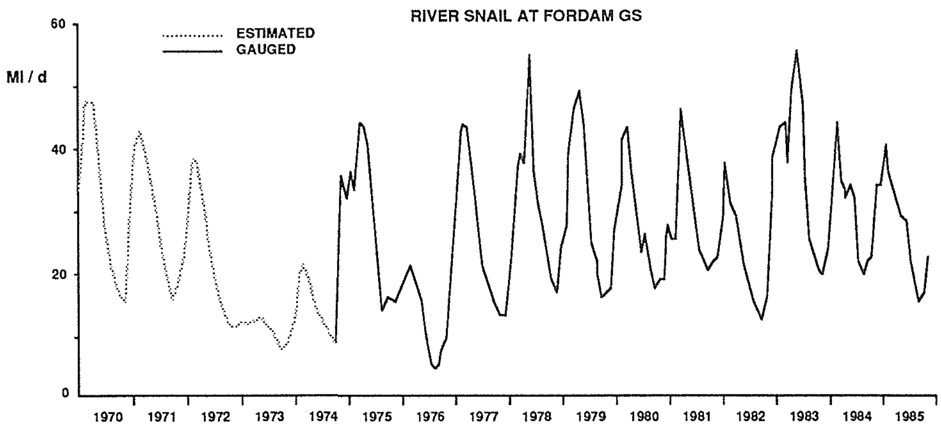


FIG. 3 Typical hydrograph of base flow in River Snail.

Maintenance of flows in these water courses is important since:

(a) water is abstracted from the Lodes for spray irrigation of high value salad crops;

(b) aquatic flora and fauna depend on the stream flows; the area contains several wetland conservation areas;

(c) flows are necessary to dilute water from sewage treatment works; water quality considerations are important in the Lodes which drain into an area for recreation including boating and fishing;

(d) the asset of an attractive stream is highly valued by the local people; conservation issues are important to many living in prosperous riparian villages.

Hydrometric data indicate that spring flows are sensitive to variations in the water table; the natural baseflow in summer is normally less than 20% of the winter flows. A typical response is shown in Fig. 3. Recovery of spring flows usually commences in late December or January reaching a peak in March or April.

## GROUNDWATER FLOW

### Important features

Recharge occurs in a number of ways:

(a) the conventional recharge mechanism applies over the Chalk outcrop area (Rushton & Ward, 1979);

(b) over the higher ground where there is boulder clay cover, a small but significant flow occurs through the boulder clay; this is assumed to equal 0.07 mm $day^{-1}$;

(c) in addition there is run-off from the boulder clay area. This run-off subsequently infiltrates into the Chalk on the boulder clay margins. The importance of this source of recharge is apparent from the fact that all the streams which carry the run-off from the boulder clay lose their flow before reaching the lower ground of the Lodes catchment;

(d) in the low lying Chalk Marl area the water table is high. During dry periods evaporation can draw water from the Chalk Marl and this is represented as a negative recharge.

As in most other Chalk aquifers, the zone of fluctuation of the water table provides regions of higher hydraulic conductivity (Rushton et al; 1989). Consequently the transmissivity reduces significantly as the water table falls. Also, the specific yield of the aquifer tends to be higher within the zone of fluctuation of the water table. When the water table is lowered due to pumping from a borehole, a rapid fall in the pumped level can occur as the water table moves below the zone of fluctuation. In a similar manner, springs are less able to attract water under low water table conditions.

There are two important flow horizons within the Chalk. As indicated by the cross-section of Fig.2 water emerges from dominant spring lines at the outcrop of the Melbourn Rock and the Totternhoe Stone. These are both bands of hard, well fissured Chalk with relatively high hydraulic conductivities. Their outcrops are indicated on the simplified geological map of Fig.1. They also provide important flow paths to pumped boreholes.

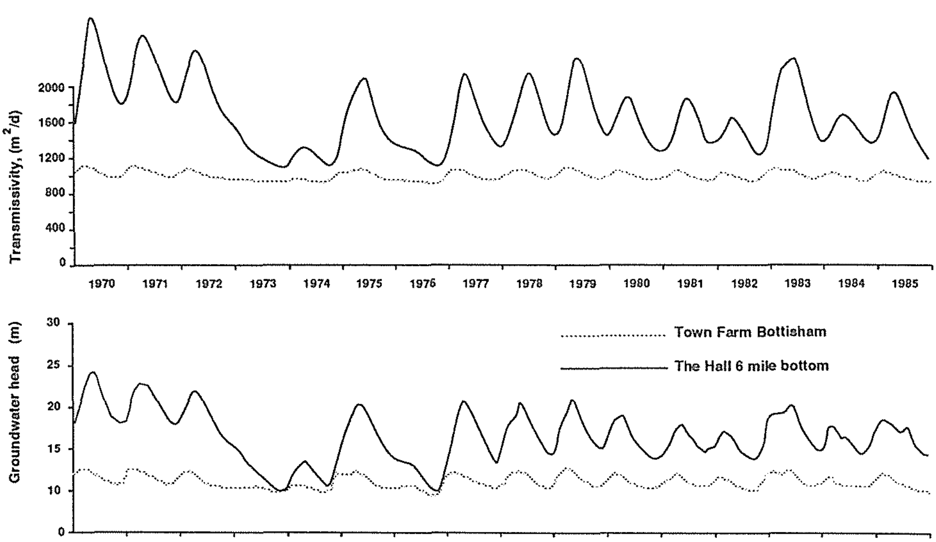


FIG. 4 Typical hydrographs of fluctuations of groundwater heads and transmissivities at *The Hall* and *Bottisham*.

The present abstractions have a significant effect on groundwater flows in the aquifer system. The distribution of the existing abstraction sites is not uniform over the aquifer. Some are positioned some distance from spring heads but others are certain to influence the spring flows. The proposed abstraction sites for public supply and river support lead to a more uniform distribution.

A mathematical model has been developed to represent the study area. The model has many similarities with that developed for the Berkshire Downs (Rushton et al; 1989). Preparation of the model led to an improved understanding of the aquifer flow mechanisms and allowed components of the water balance to be quantified. A period of 17 years (1970-1986) has been simulated successfully.

## Flow mechanisms

The aquifer flow mechanisms have an important effect on the variation in stream flows and groundwater heads. Two representative hydrographs are selected to illustrate the aquifer response. Figure 3 contains a flow hydrograph of the River Snail and Fig. 4 shows the variation with time of the groundwater head and transmissivity (as predicted by the mathematical model) at two observation wells. In examining these figures, certain features are apparent:

(a) the flows in the River Snail show significant seasonal fluctuations, exceeding 50 Ml $day^{-1}$ during periods of high recharge but falling to below 10 Ml $day^{-1}$ during dry periods;

(b) at the Hall observation borehole, which is in the region between the boulder clay cover and the springs, fluctuations in groundwater head approach 15 m. Transmissivity values deduced from the numerical model average 1800 $m^2$ $day^{-1}$ with variations of about 700 $m^2$ $day^{-1}$. Low spring flows coincide with low groundwater heads;

(c) at Bottisham observation borehole, which is in the vicinity of the Totternhoe Stone springline, the transmissivity is high but the groundwater head and transmissivity fluctuations are both small due to the influence of the neighbouring springs.

From these and other hydrographs, it is possible to devise schematic diagrams which illustrate the differences between groundwater flow conditions under high and low groundwater heads (Fig. 5). In the first diagram, the water table and also the transmissivity are high in the region between the boulder clay cover and the springs and therefore large quantities of groundwater move towards and flow from the springs. However, during dry spells when the groundwater heads in the intermediate region are low, the gradients and transmissivity are reduced and therefore the spring flow is low.

These conditions can be illustrated further by considering the flow balance for the last quarter of 1974 and each quarter in 1975-76 (Fig.6). Detailed comments are made on the diagram and they should be examined carefully to understand the complex responses within the aquifer system. The results confirm that the spring flows are small unless the head gradient *and* transmissivity are sufficiently large to transmit the groundwater to the springs. On the other hand, if substantial recharge occurs when the groundwater heads and transmissivity are high, water is transmitted rapidly towards the springs rather than being stored in the aquifer. Each of the nine balances illustrates different aquifer responses.

Over the period of 17 years for which the model was run the overall water balance showed that the average abstraction is little more than half the average recharge. However, because a substantial part of the recharge flows quickly to the streams and springs, the water remaining in the aquifer during dry periods is limited.

Towards the end of the dry period in 1976, the performance of certain boreholes was limited by low water levels. The facility

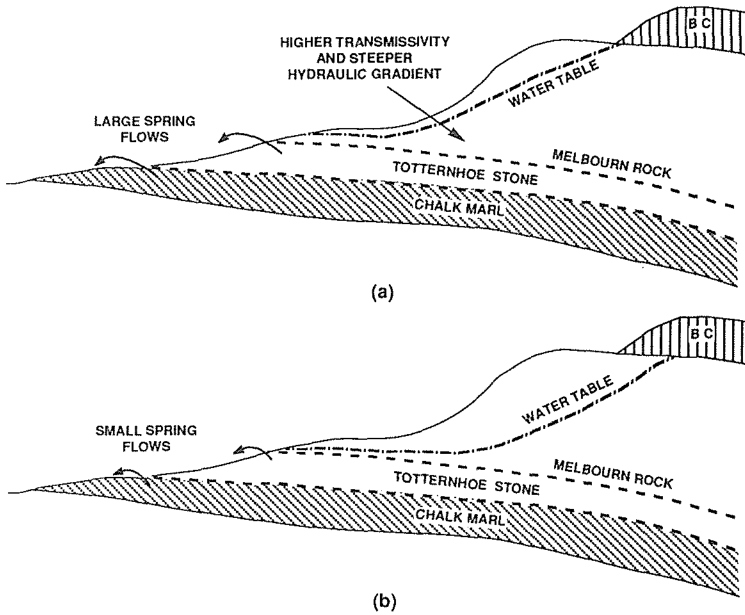


FIG. 5 Flow conditions under (a) high and (b) low water levels.

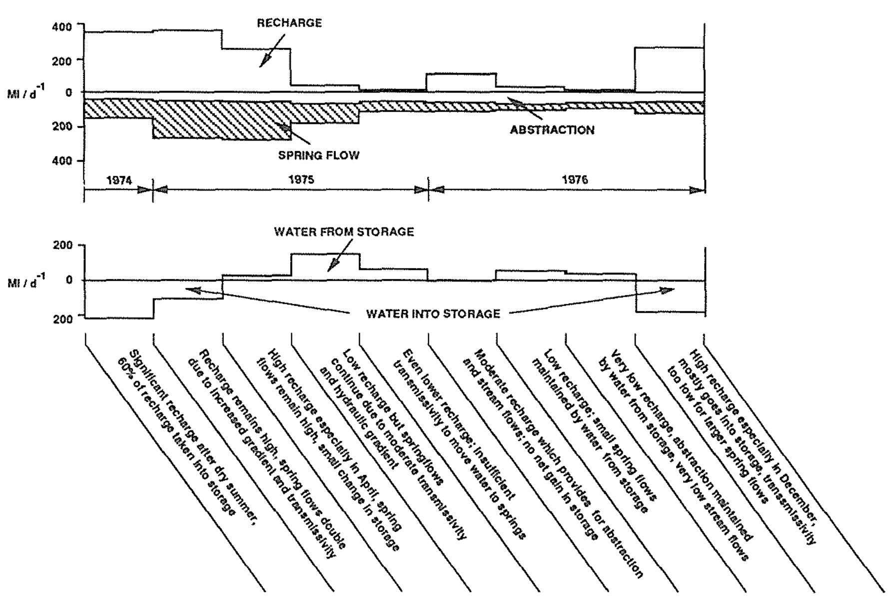


FIG. 6 Three-monthly flow balance under historical conditions.

within the model to restrict borehole yields if the groundwater levels fell too low proved to be important when assessing the impact of the proposed new sources.

## GROUNDWATER DEVELOPMENT

### Additional abstractions for public supply

Chalk groundwater is relatively cheap and of high quality. The two water companies with existing sources in the area wish to make maximum use of the aquifer and had proposed additional abstractions. However, it was felt that additional abstractions would further reduce streamflows and in certain locations this would be unacceptable. River support was seen as a possible solution.

### The River support scheme

In-stream requirements were assessed for each of the watercourses. These were based on water balance calculations working upstream from the Lodes and taking into account:

(a) the required flow at the end of the Lodes where they discharge into the River Cam;
(b) licensed surface water abstractions (predominantly spray irrigation);
(c) demands for subsurface irrigation;
(d) discharges from sewage treatment works;
(e) flow requirements to maintain designated sites of special scientific interest;
(f) flow requirements to maintain water quality objectives.

The in-stream requirements were associated with target flows at seven gauging stations at key locations. Operation of the river support scheme will be based on maintaining these flows. If the gauged flows fall below the target flows the deficit will be made up with water pumped from river support boreholes. The river support boreholes are located some distance from the springheads in order to avoid interference, but at positions where there is a reasonable depth of aquifer and satisfactory transmissivity.

### Results from the groundwater model

The mathematical model was used to examine the feasibility of developing additional abstractions in conjunction with river support to compensate reduced streamflows. The proposals as modelled are shown schematically in Fig.7.

Initially historical abstraction and recharge values were used to simulate 17 years from 1970 to 1986. Comparison of modelled streamflows with the proposed target flows showed that the streams would have needed support for 67 of the 204 months. The important implication of this finding is that river support will enhance the existing low flow regime.

An identical run but this time incorporating abstractions from the river support boreholes showed that the river support requirements could have been met without affecting the existing public supply boreholes. The maximum requirement for river support in any one month totalled 7.2 Ml day$^{-1}$ (compared to an average abstraction for public water supply of 55 Ml day$^{-1}$). Following very dry periods, most of the recharge went to refill storage before significant lateral groundwater flows occurred and consequently river support continued for several months after the onset of recharge.

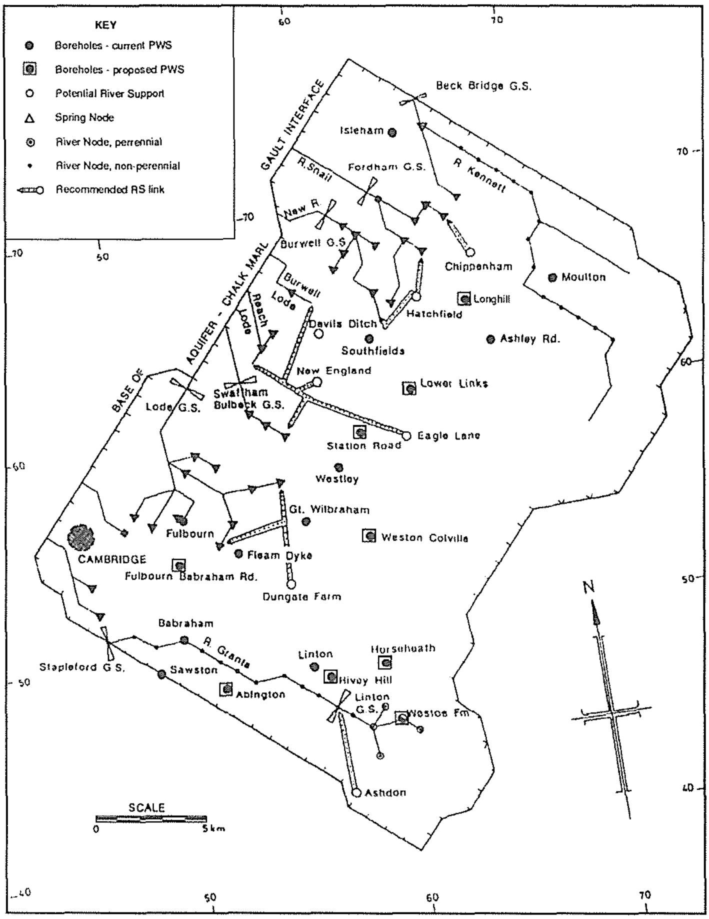


FIG. 7 Layout of the River Support Scheme.

Numerous model runs were made to evaluate various combinations of river support and additional abstraction. In one an increase in abstraction to 74 $Mld^{-1}$ was examined, involving a redistribution of demands by closing 3 of the 14 existing sources and the construction of eight new ones. Seasonal demand factors were used to increase demand in Summer and reduce it in Winter. The same simulation period with historical recharge from 1970 to 1986 was used. Results from the model showed that:

(a) for most of the time the river support boreholes would have continued to function satisfactorily, with support required for 94 of the 204 months. The maximum monthly demand totalled 12.1 Ml $day^{-1}$. Certain sites would have needed support for much longer than others. Target flows at some of the gauging stations could not have been maintained in full during extreme conditions due to low pumped water levels at certain river support boreholes;

(b) similarly some of the public supply sources would not have been able to meet their full demands at certain times. The greatest shortfall during a dry period with peak summer demands would have been approximately 6% of the average monthly abstraction over the whole study area.

It should be noted that the borehole "failures" were based on threshold levels which may be somewhat conservative. Until all the boreholes are drilled and operational their true reliability will not be known.

### The Lodes-Granta groundwater scheme

The results of the modelling investigation were used by the NRA in making decisions about the additional public supply abstractions, in designing the river support scheme and during consultation with interested parties. The scheme is now under construction. The model has identified certain boreholes where reliability problems may be experienced and particular attention will be paid to these sites.

The scheme involves six new boreholes for river support, supplying water to 13 springheads via 44 km of pipeline. The maximum output from the scheme will be 21 Ml $day^{-1}$ but the long term average requirement for river support will be only 2.0 Ml $day^{-1}$. This will permit additional abstractions which average 14 Ml $day^{-1}$, increasing the licensed total for the study area to 87 Ml $day^{-1}$.

## CONCLUSIONS

This paper has described a feasibility study for a river support scheme. The study considered the aquifer flow mechanisms and demonstrated that a significant proportion of the recharge flows quickly to the springs and streams when the water table (and hence the transmissivity) is high. This recharge is not available to maintain spring flows throughout the following Summer. Spring flows are therefore particularly sensitive to additional abstractions and would be affected in most years.

A mathematical model has been developed to represent the aquifer and used to investigate options for river support. It is possible to compensate reductions in springflows by pumping water from the aquifer to maintain target flows in the streams. The seasonal requirements for river support are relatively small in comparison to the continuous abstractions which are consequently made available for public water supply.

The river support scheme is now under construction. It has been possible to manage the water resources of the area in ways to benefit all concerned. The provision of increased water for public supply will not be at the expense of low flows in rivers, streams and wetland conservation areas.

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