If The NAPI Fits……..

Jamie Margetts

WS Atkins Water, Brunel House, RTC Business Park, London Road, Derby, DE1 2WS, UK

1 Introduction

The New Runoff Model (NR) is frequently used in modelling studies, and often provides an improved verification compared to its predecessor, the Wallingford (Old PR) model. The Old PR equation tends to underpredict runoff for areas with a low percentage impermeability, and various 'fixes' have been developed to address this (e.g. the 10m rule). The NR equation is also frequently utilised to model the prolonged recessions observed in a flow hydrograph due to rainfall responsive infiltration or delayed runoff from pervious areas, though the most important feature is it has the ability to represent the increasing wetness of a catchment during the course of a rainfall event. As highlighted in WaPUG User Note 28 (revised edition) it is also a more robust method of calculating runoff as it treats impermeable and permeable surfaces separately, and unlike the Old PR Model (Wallingford Model) it can be used in continuous simulation as the catchment wetness is updated continuously throughout the course of an event.

The latter part of the 1990's has seen the increased uptake of the NR Model in modelling studies. However, many modellers have been reluctant to use the NR Model, due to the uncertainty relating to its application to design events. At present, there is little clear guidance on how to choose design NAPI values, mainly due to the fact that the water industry has yet to formulate a working procedure. In addition, many modellers expect to see clearly defined charts and graphs, as are available for UCWI values, which at present are not yet available for NAPI values.

This lack of guidance, however, should not limit the use of the NR Model, as it is possible to determine catchment specific design NAPI values, which are as robust as the 'set in stone' design UCWI values used with the Wallingford Model. As described in this paper, it may also be possible to develop a nationwide set of parameters that allow the design NAPI value for a particular catchment to be estimated, in a similar fashion to the current procedure for determining design UCWI values.

This paper will describe and compare a number of methodologies that have been used for determining design NAPI values. These methodologies will first focus on the derivation of design NAPI values on a catchment by catchment basis. The possibility of developing regional, or national, charts that can be used to approximate design values of NAPI for different catchments or soil types will then be investigated. A first attempt at developing such general design charts will be presented.

This paper is loosely based on the methodologies presented in WaPUG User Note 28, but attempts to take this a step further by adding more detail in terms of sensitivity issues and test data. It is also highlighted that the first moves to set up a working group to address the issues of design NAPI have been made early in 2002, and this paper is designed to highlight many of the issues that should be considered by the group.

2 Method 1 – Correlation of UCWI and NAPI values

As part of the Prestwick DAS study, carried out by WS Atkins, StormPAC was utilised to generate a typical year time series of stochastic rainfall. This series was based on historic data, for use in the CSO performance analysis. One of the advantages of StormPAC is that it calculates an event specific UCWI and NAPI value for each of the generated rainfall events within a series. Whilst this is ideal for the time series analysis, it does not answer the question of what antecedent conditions to use for synthetic design storms if using the NR equation. In the Prestwick case, the calculated UCWI and NAPI values for each of the stochastic events contained within the time series were extracted and subsequently regressed. This was carried out for both winter and summer storms (in relation to bathing season period), and in total contained 239 stochastically generated rainfall events. The resulting correlation is highlighted in Figures 1a and 1b.

The design UCWI value was then calculated in the usual manner based on the Wallingford Procedure, and an estimate of the design NAPI value taken from the chart. In this case, a summer design UCWI of 105 produced a design NAPI value of 8.2, and a winter design UCWI of 145 produced a design NAPI of 18.69. It is important to stress that these values are based on a soil type of 4, and a summer evaporation of 3 mm/day and winter evaporation of 1 mm/day was used.

It is clear to see from Figures 1a and 1b that the relationship between UCWI and NAPI value does show a significant amount of scatter. This is due to the difference in the amount of rainfall used in the UCWI and NAPI calculations. UCWI values are a function of only 5 days preceding rainfall, whereas NAPI values are based on the 30 days preceding rainfall. As Prestwick is predominantly soil type 4, the effect of rainfall more than 5 days previous is important. For example, a specific day may have a low calculated UCWI value (due to low rainfall in the preceding 5 days) but may have a relatively large NAPI value due to significant rainfall between, say, preceding days 7 to 10, or even 15 to 20. Further work relating to the effect of weightings of rainfall distribution with respect 30 and 5 days would be useful.

For soil types 1 or 2, where the decay factor k in the NAPI calculation is much lower, the UCWI / NAPI relationship is likely to be much more robust, due to the relative importance of the preceding 5 days rainfall for such soil types.

Whilst this approach did not produce an ideal relationship, it did provide an estimate of the design NAPI value based on engineering judgement / analysis. More importantly, it required a crude statistical assessment of catchment specific NAPI values, thus allowing the user to make a judgement on the range of NAPI values at the start of all the storms in a typical year and formulate a sensitivity analysis to test the initial design estimate of NAPI.

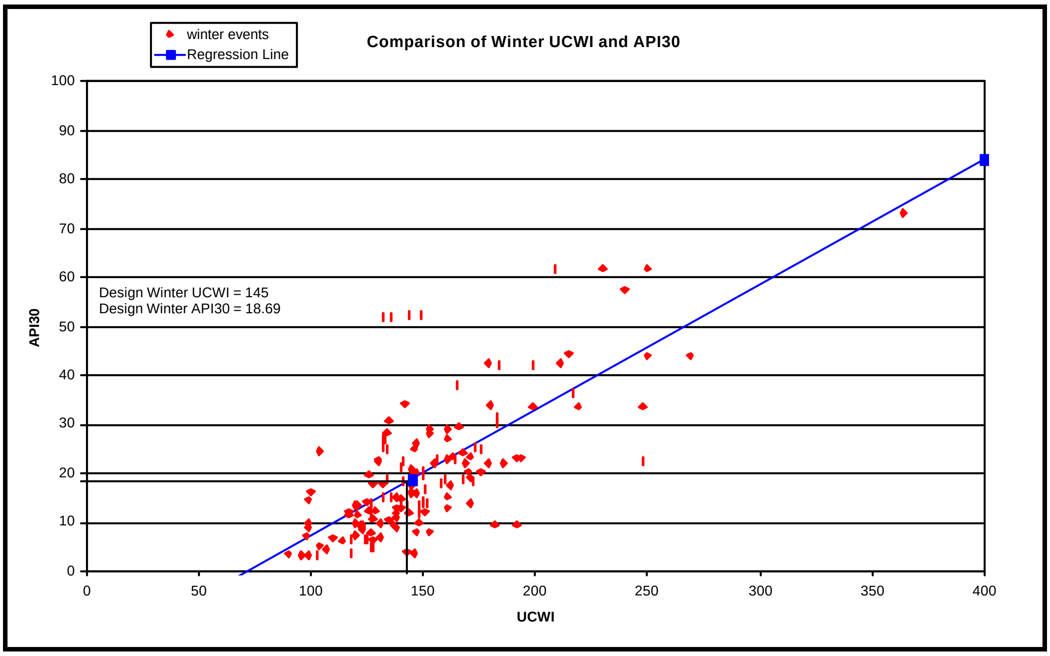

Figure 1a Correlation of winter UCWI and NAPI values for Prestwick

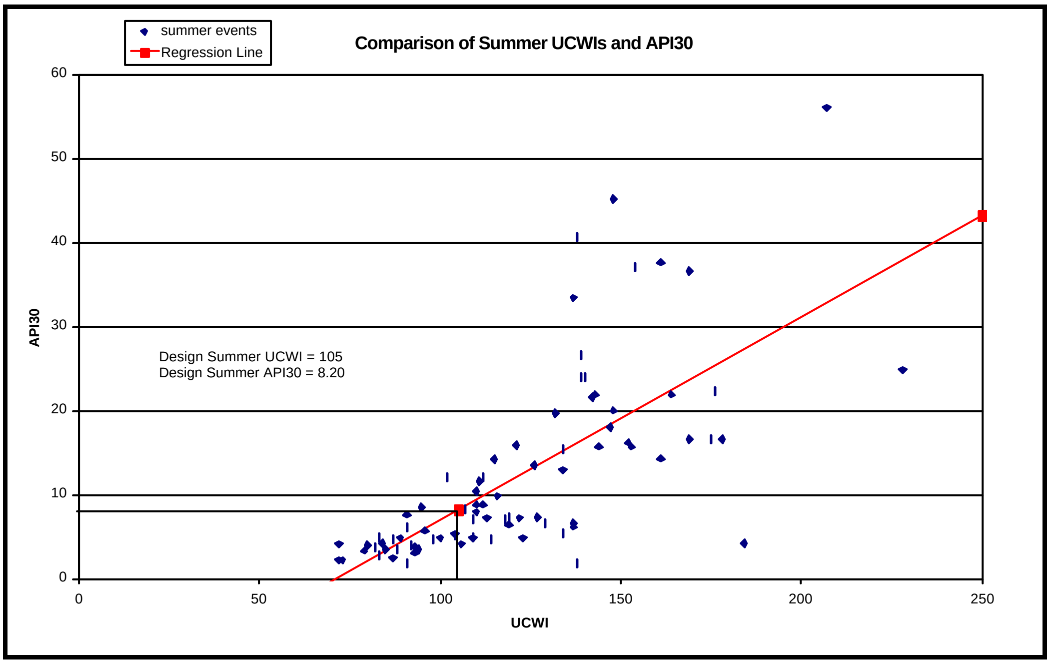

Figure 1b Correlation of summer UCWI and NAPI values for Prestwick

It is highlighted that this methodology has not been carried out for other catchments and soil types as part of this study. An assessment of correlations with regard to sensitivity between different soil types would be useful.

3 Method 2 – Analysis of rainfall data

The second, and perhaps more robust, method to determine a design NAPI value is to simply analyse as large a set of rainfall data as possible. This is the preferred methodology in WaPUG user note 28 (revised edition). Ideally, historic data should be used to base an estimate of NAPI, however, in some cases only stochastic rainfall data may be available. However, historic data should generally be available where stochastic data has been generated, as historic rainfall data is a pre-requisite for well generated stochastic data.

Perhaps the best methodology would be to calculate the NAPI value for every day in a historic series (ideally 20 years) and base the design value on some pre-determined percentile. The original Wallingford Procedure calculated the design UCWI as the median value in a data set. As this is widely accepted in terms of the Old PR Model, then this is an ideal starting point on which to calculate the design NAPI value based on historical rainfall data. This is relatively simple to carry out, and providing rainfall data is available, can be carried out on a catchment by catchment basis as the need arises.

There are, however, a range of issues that should be considered before simply using the median NAPI value from a rainfall series. These should be assessed on a catchment, and thus client basis, and include:

- Is the median suitable for design? – this is the most obvious consideration, as the choice of initial percentile obviously affects the resulting design NAPI. Different design criteria, and required factors of safety, may require a different percentile to be used. The analysis carried out to determine design UCWI values did not consider this, and the median was used throughout. Should an industry wide agreement be reached or should this be determined on an ad-hoc basis for each study? The answer to this question may also be linked to whether we should now be designing to flood return periods or rainfall return periods.

- Consideration should be given as to whether to base the median value on the NAPI from each day in the series, or whether to base it on only the NAPI values calculated on days where there is rain (i.e. events) within a series. The former scenario assumes that rainfall is likely to happen on any day during the year, and thus any design value should include all days in the series. The latter scenario, as recommended in WaPUG user note 28, assumes that as it is the NAPI at the start of a rainfall event that is being determined, then only NAPI values on days where there is rainfall should be considered in the empirical analysis. This then throws up the obvious question as to what should be considered an event or ‘day with rainfall’ in order to base the NAPI calculations. WaPUG User Note 28 suggests a 5mm depth criteria for determining rainfall events, though some users are focussing on events over 10mm depth. The knock on of this is: should we consider the full range of antecedent conditions, or just those prior to rainfall events? Subsequently, does design NAPI value vary with the return period of the storms within the base data, and should different design values be used for synthetic design events with differing return periods?

Table 1 compares the NAPI values calculated for Prestwick based on the above methods. It is clear to see that the various methods (UCWI / NAPI correlation, median of stochastic data, median of historic data) give relatively similar results, although differences are greater in winter. Also presented in Table 1 are design NAPI values based on percentiles other than the median value. As expected, these have a significant affect on the calculated design NAPI value. The choice of the design percentile would have obvious implications on the size and scale of any resulting improvement schemes (especially storage).

	UCWI / API correlation	Median based on stochastic data	Median based on historic data	25%ile historic data	75%ile historic data	95%ile historic data
Summer	8.2	7.25	8.66	3.67	15.81	29.47
Winter	18.69	16.8	20.32	10.53	31.31	50.80

Table 1 Comparison of design NAPI values from different methods (Soil Type 4)

Table 2 shows the effect of basing the design NAPI on the median of every day in the year, or the median of the NAPI value calculated only for days with rainfall. Different rainfall criteria have been used, as some would argue that as the design NAPI values are to be used for design rainfall, which is generally over 1 year return period, then only very wet days should be used in the analysis . Whilst each method gives a relatively similar value, there is a definite increase in design NAPI value when the base data is manipulated to include only rainfall events. This supports the theory of storm clustering, where rainfall events are more likely to occur following other events, rather than simply at any time during the year. The ratio of summer to winter NAPI is relatively constant, irrespective of rainfall criteria, indicating that the storm clustering does not have a larger influence in the winter than the summer, though this would need investigating on a number of sites as it appears counterintuitive.

	Median – every day	Median – days > 0.1mm	Median – days > 2mm	Median – days > 4mm	Median – days > 5mm
Summer	8.66	10.99	11.75	11.86	12.04
Winter	20.32	23.83	25.53	26.07	26.77

Table 2 Design NAPI values and event selection from historic data (Soil Type 4)

4 The importance of Evaporation

WaPUG User Note 28 recommends that where detailed evaporation data is not available, then approximations of 1 mm/day and 3 mm/day evaporation should be used to calculate the NAPI values. In reality, evaporation varies significantly on a monthly basis. As a result, it is strongly recommended that evaporation values be obtained at the same time as obtaining historic rainfall data (and thus reduce the cost). Daily evaporation rates may significantly increase the cost of obtaining the required rainfall data, but alternatively, long term monthly average evaporation rates could be obtained relatively inexpensively. Simple models such as the Penman model are also an acceptable alternative, or evaporation could even be calculated purely as a function of temperature and humidity data, which is relatively easy to obtain. Figure 2 highlights the effect of using long term monthly evaporation rates, actual monthly evaporation rates, and the 1 mm/day and 3 mm/day assumptions on the 1990 NAPI values for Walsall Wood. It is clear to see that 1 mm/day is appropriate for the winter scenario, but 3 mm/day appears to be a too high assumption for the summer scenario. This results in the design NAPI values being too low for the summer condition when the 3 mm/day is assumption is utilised. Where possible, actual evaporation rates should be sought.

A reassessment of evaporation approximations may be useful, with the 3 mm/day representing the hottest summer months of July and August, and then a reduced value for other summer months. An assessment of long term evaporation records, for different catchments, would be particularly useful to re-examine these approximations.

all values in mm/day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Long term Monthly	0.40	0.77	1.29	1.80	2.06	1.88	1.68	1.48	1.39	1.04	0.54	0.39
Actual Monthly	0.56	0.99	1.20	1.50	2.35	1.63	1.39	0.76	0.56	1.18	0.52	0.32

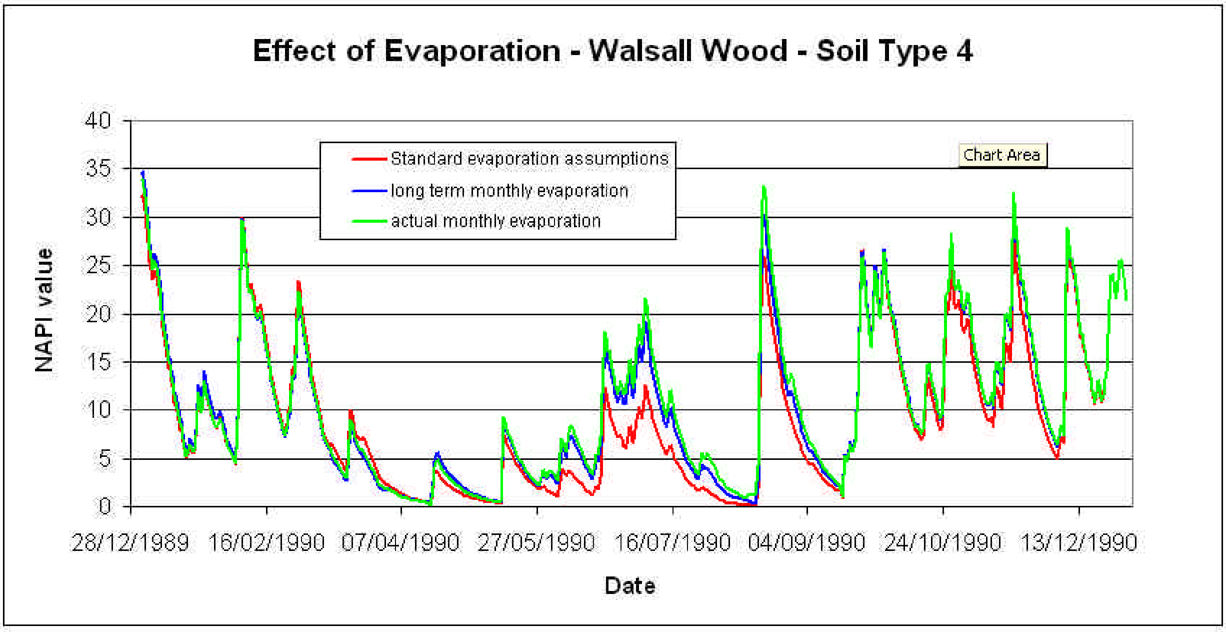

Figure 2 The effect of Evaporation

The effect of this on the median is highlighted in Table 3, and is quite significant, even though the evaporation rates do not seem to vary a great deal between the different sources of evaporation data. The anomaly between assumed evaporation rates and measured values is far more important in the summer in this case (by up to 50% on the median values). However, similar effects with regard the winter scenario cannot be ruled out in other areas and this should be investigated before the '1 and 3 mm/day assumption' is used.

Scenario	**'1 + 3 mm/d' assumption**	**Long term monthly data**	**Actual monthly data**
Summer	3.47	5.07	5.66
Winter	10.83	11.59	11.70
All Year	7.38	8.70	9.07

Table 3 Effect of source of evaporation data on design NAPI – Walsall Wood

5 General Design Curves

The above discussion illustrates possible methods to determine design NAPI values, and outlines a number of issues that should be considered when utilising them. However, the above methods do rely on catchment specific long term historic or stochastic data which is not always available for a study or a model. Since the development of the Wallingford Procedure, there have been design curves for determining design summer and winter UCWI values, based on the SAAR of the catchment. Median UCWI values were correlated against SAAR for 34 sites throughout the UK. Whilst these were judged to 'correlate well', there is a significant amount of scatter for the summer values. Despite this, these curves have formed the basis of determining design UCWI values throughout the UK water industry without question. There are, as yet, no similar tables or charts for design NAPI values. Whilst catchment specific data and analysis should be the preferred method of determining design NAPI values, general charts are important for catchments with little historic data, and in terms of user friendliness and ease of use of the New Runoff Model. The reliance on the original UCWI charts by the water industry in general, rather than carrying out catchment specific design UCWI studies, proves that such tables for NAPI values would be of great benefit.

As part of an experimental study, long term (up to 20 years) historic rainfall series were obtained for 20 sites throughout the UK (Within the Severn Trent and Scottish Water regions). Generally, the areas with a higher SAAR were located in north and central Scotland, and those with the lower SAAR (< 800mm) were located within the Severn Trent region. NAPI values were calculated for each day within each series, for each of the 5 soil types. Median summer, winter and full year NAPI values were then determined for each. Summer was classified as the beginning of May to the end of September. Evaporation was taken at 1 mm/day for the winter days, and 3 mm/day for summer days, as no actual evaporation data was freely available at the time of the study. The SAAR was also determined for each site based on the long term rainfall series.

A frequently encountered problem in this analysis was that of missing rainfall data within the databases, especially in less populated locations. Assumptions were made relating to this missing data, and this generally took the form of replacing a series of missing values with the corresponding values from the proceeding year. The sites used covered a range of SAAR (650mm – 1300mm), though the data set is by no means complete. There is an obvious gap of data between 1000 and 1200 mm, and the need for data for sites with SAAR greater than 1350mm.

It is also highlighted that no adjustment of NAPI values has been carried out based on the duration of the storm. This is recommended in WaPUG User Note 28, to allow for the likelihood of earlier rainfall. As the analysis in this paper has been based on the median of all days in a series, this adjustment was not carried out. Due to time constraints in producing this paper, no investigation has been carried out to assess the affect of this adjustment.

Figures 3a to 3e highlight the relationship between SAAR and median NAPI value for each soil type.

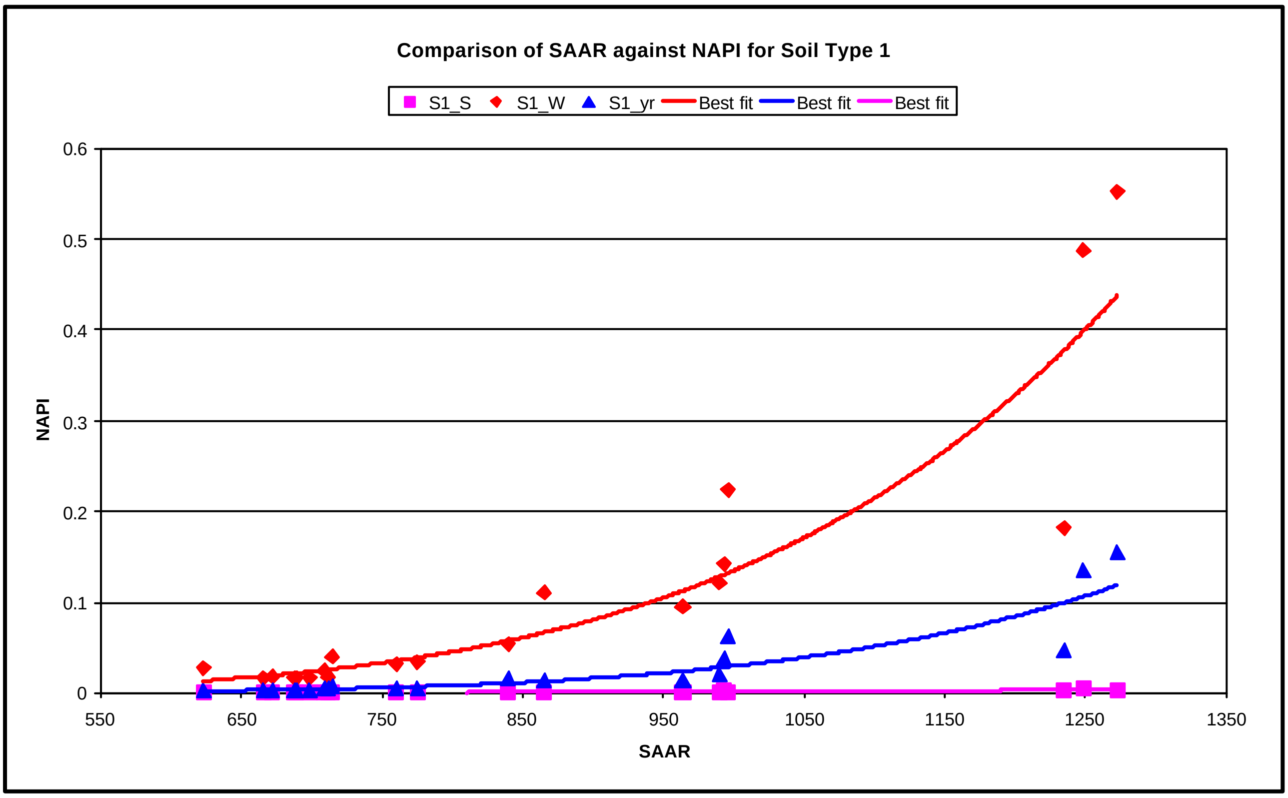

Figure 3a Comparison of SAAR against median NAPI – Soil 1

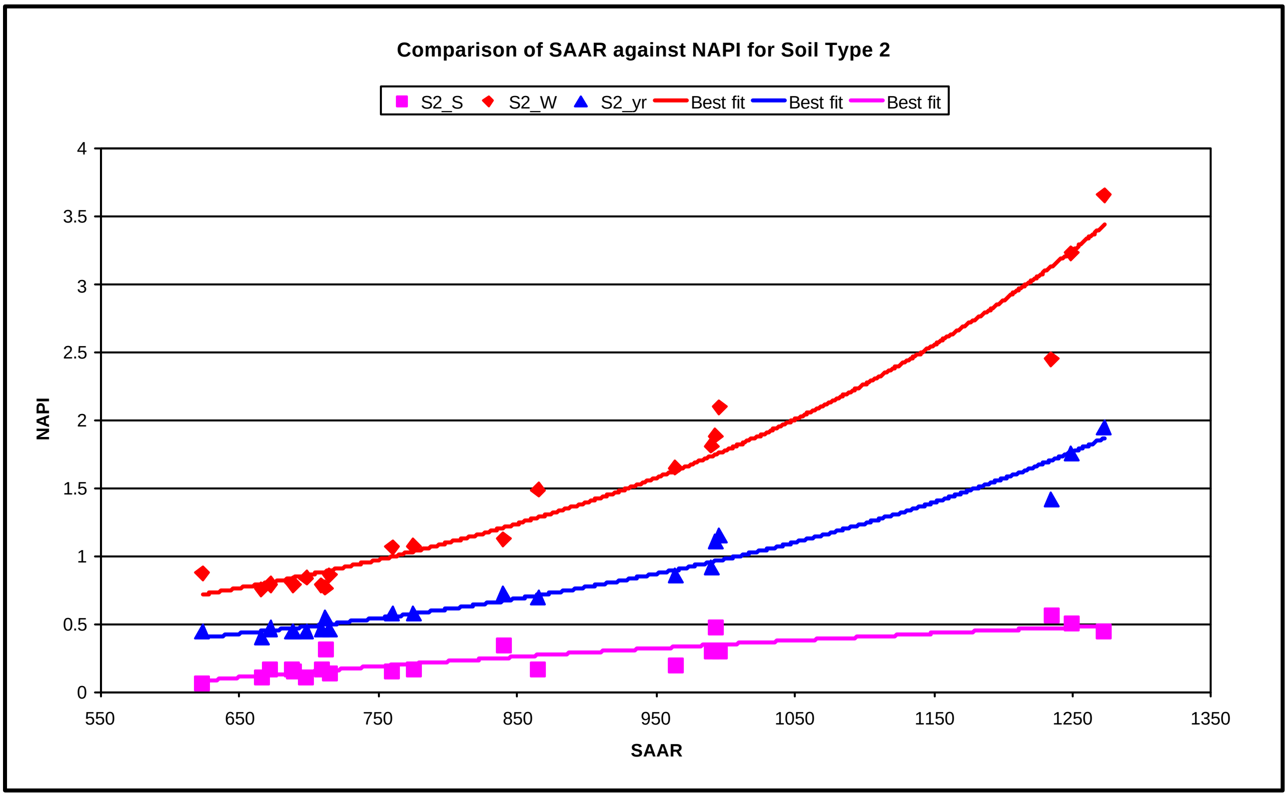

Figure 3b Comparison of SAAR against median NAPI – Soil 2

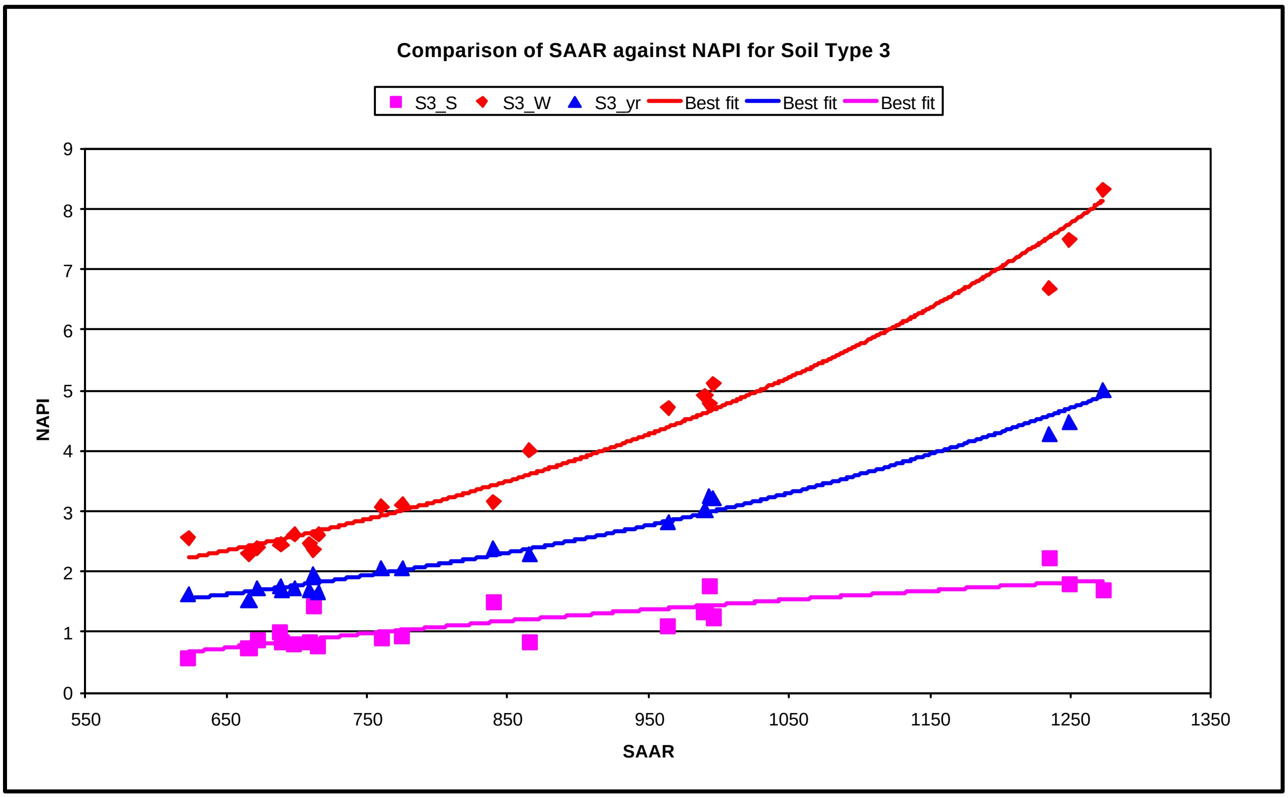

Figure 3c Comparison of SAAR against median NAPI – Soil 3

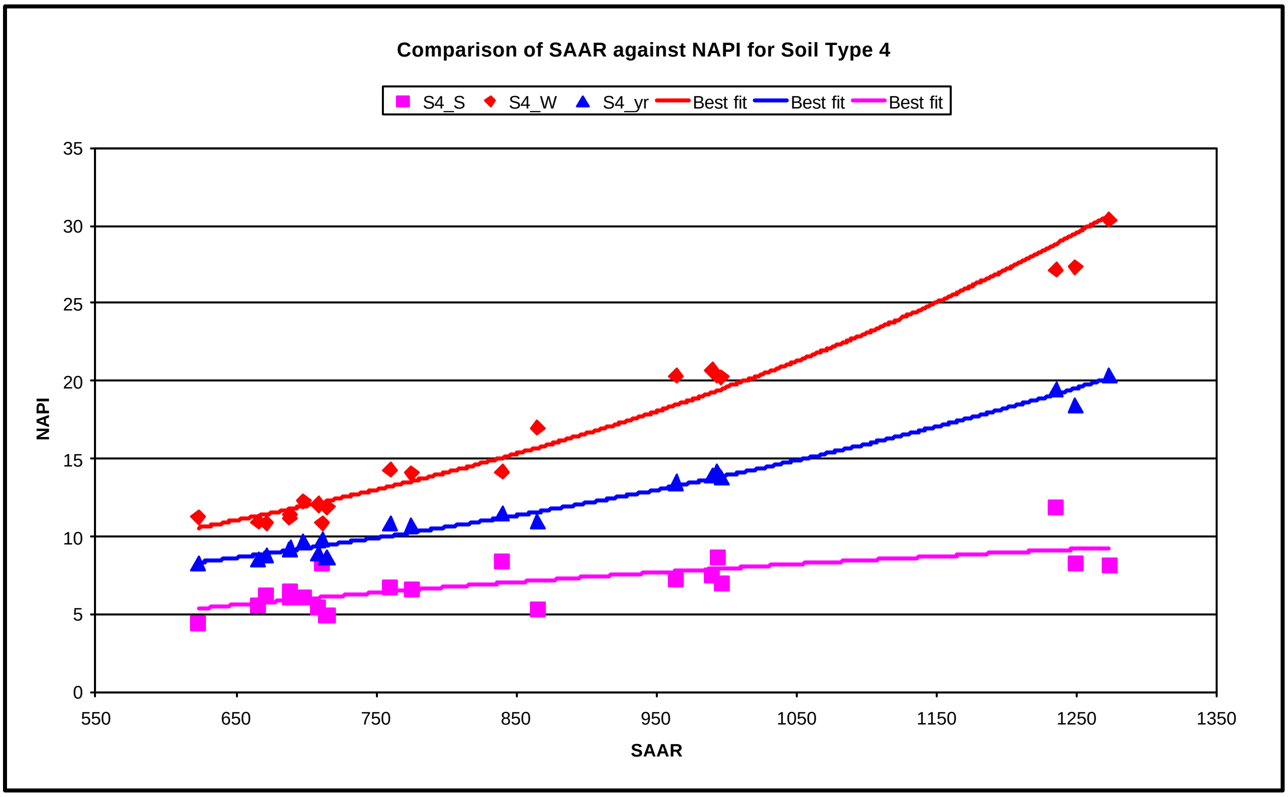

Figure 3d Comparison of SAAR against median NAPI – Soil 4

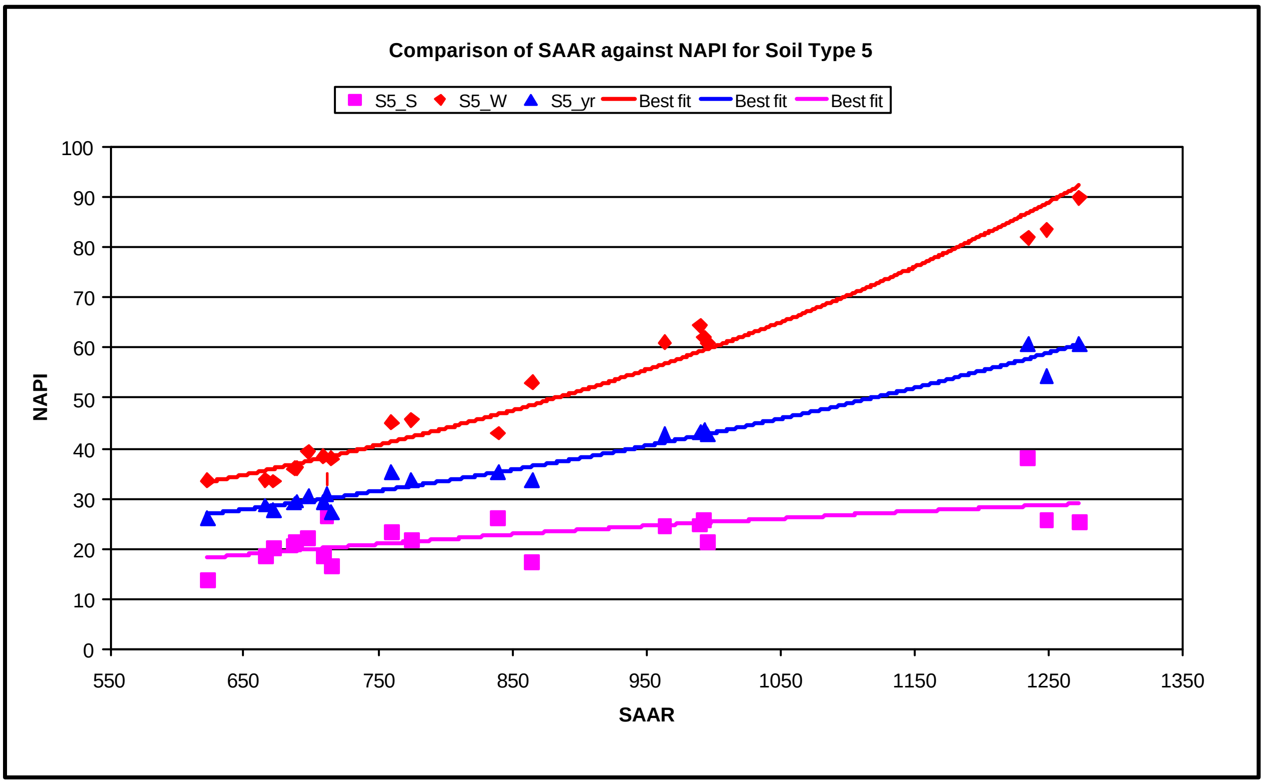

Figure 3e Comparison of SAAR against median NAPI – Soil 5

A number of key points can be drawn from these charts:

1. There does appear to be clear relationships between SAAR and median NAPI value, for each soil class. The R^2 value for the winter and full year values is consistently above 0.95.

2. There is a much greater increase in NAPI with SAAR for the winter scenario than for summer, as would be expected due to the increased rainfall (and lower assumed evaporation rates) in winter periods.

3. The median summer NAPI is relatively insensitive to SAAR, and the linear relationship is almost horizontal. This may be a function of the 3 mm/day evaporation assumed for all summer events, which acts to dampen out the affect of frequent small storms. In areas of higher SAAR it may be inappropriate to assume a 3 mm/day evaporation throughout all the summer months.

4. Are design curves required for soil type 1? In the case of soil type 1 the median NAPI value is always less than 1, irrespective of SAAR. A sensitivity analysis was carried out using a simple model containing 10 ha of pervious area (as NR model) and simulated for a range of soil types and design NAPI values. Figure 4 presents the runoff volumes from this test scenario for the various NAPI values. Increasing the NAPI value from 0 to 1 (which equates to the range of design NAPI values from the soil type 1 chart) resulted in a 10% increase in runoff. In contrast, an increase in NAPI from 0 to 30 (which equates to the range of design NAPI values from the soil type 4 chart) results in a 400% increase in runoff volume. This confirms the increasing sensitivity, and thus importance of choice of design NAPI, for the wetter soils (Types 3-5).

Despite these encouraging initial results, it should be stressed that the sites used in this analysis are from two distinct areas in terms of rainfall characteristics. It is strongly recommended that the next step in the generation of these design curves be to include rainfall data from many more areas across the UK, taking into account various factors which give rise to spatial variability in rainfall characteristics (topography, altitude, distance from coast, west / east location). It may be that, a number of more 'regionalised' curves are appropriate that account for factors such as these. This, though, will require significant investigation, and will only be possible when a more extensive database is available.

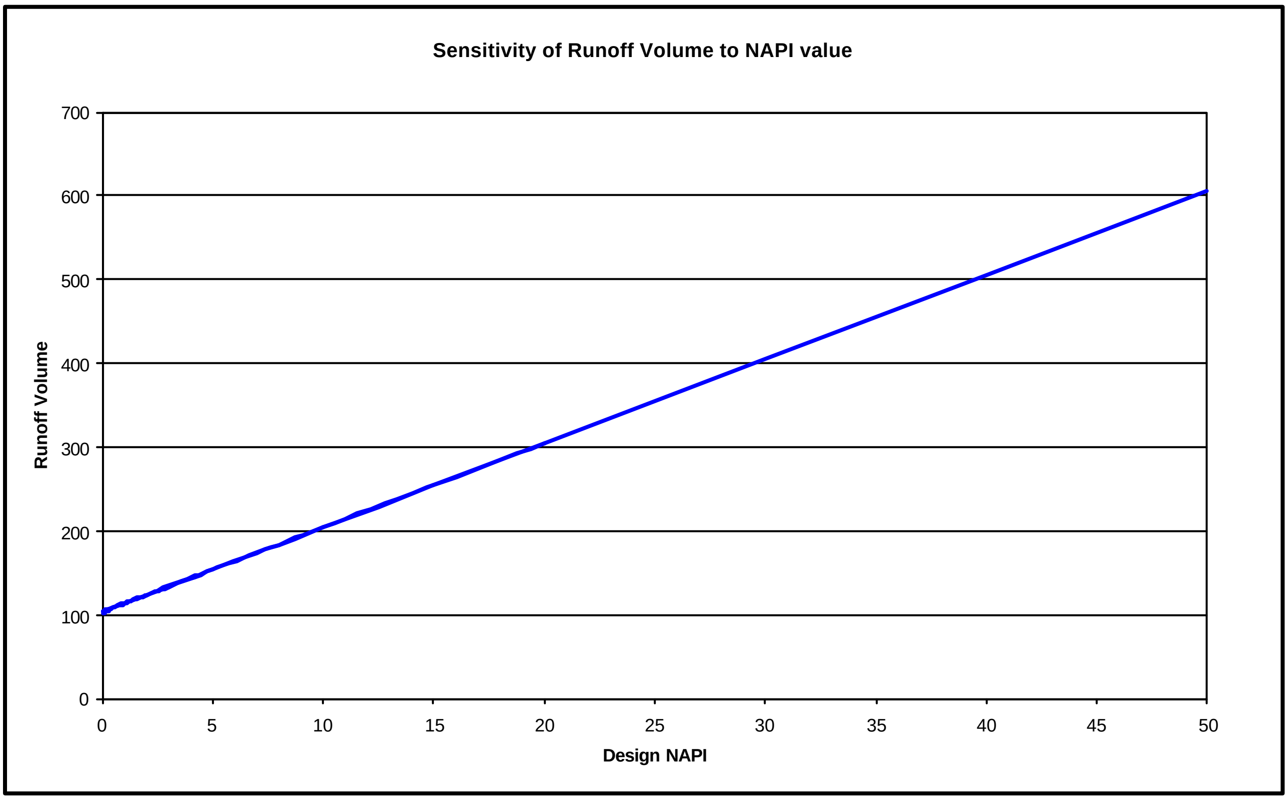

Figure 4 Sensitivity of runoff volume to NAPI value

6 The Next Step

These experimental curves confirm that there would be merit in forming an industry wide working group to carry out analyses for a variety of sites. The curves presented here are by no means the end product, as they are based on only 20 sites throughout the UK, however they form a useful starting point on which to begin a nationwide study.

A number of important requirements can be drawn from this review:

- Industry wide agreement relating to the statistical parameters used to analyse long series of rainfall and thus NAPI values is required. Should we use the median or would a higher %ile be more appropriate for design purposes? Are standard assumptions on evaporation appropriate, or should more detailed data be utilised? Should median values be based on all days in a series or only days with rain? Should we still base design curves on summer and winter differentials, or are annual curves adequate? How should we address the problem of missing data in historical data sets?

- Industry endorsed recommendations guiding users to the best and most appropriate methods to determine design NAPI values are required. For example, if catchment specific data is available then use that, alternatively we have to begin looking at generalised design curves. WaPUG User Note 28 (revised edition) partly addresses this, however, a more detailed publication with case studies and data addressing sensitivity issues would be desirable.

- Industry wide collaboration is required to form a pool of data from a variety (and large number) of sites so that similar relationships to those presented as part of this study can be devised. A standard analysis tool, to allow the assessment of many large data sets to be carried out relatively simply, would also be a benefit.

What this study has shown is that the process and methodology for generating design NAPI values is relatively straightforward. The key requirement is co-operation, data, and funding!

7 References

Osborne, M (2000) Runoff Models – Lessons from study audits

Osborne, M (2002) WaPUG User Note 28

The Wallingford Procedure For Europe (2000) Best practice guide to urban drainage modelling

8 Acknowledgments

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