"PONDSIZER": A FREE APPLICATION FOR SIZING ATTENUATION PONDS, SUMPS AND SETTLEMENT LAGOONS

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ABSTRACT

A new Windows-based user-friendly application *"PondSizer"* is described for assisting in the design of water management structures. The application can be downloaded freely from the GWP website (www.gwp.uk.com/research.html) and used by anyone with a copy of the FEH CD-ROM. PondSizer calculates the dimensions of attenuation ponds and settlement lagoons, or sumps with pumped outflow, for prescribed design rainfall events and locations within the UK. Additionally it calculates the 'greenfield' runoff frequently required in flood-risk and hydrological-impact assessments. The user is able to specify the design event in terms of return periods, storm durations and profiles, with allowance for climate change enhancements. A graphical user interface facilitates the selection (through drop-down menus, buttons and forms with prompts) of appropriate data and parameter values (*e.g.* surface types and runoff model, *etc*) needed for the calculations. The interface is designed so that the application can be used by relatively inexperienced users.

Hall, R.L. and Reed, S.J. 2010.
"PondSizer": a free application for sizing attenuation ponds, sumps and settlement lagoons.
pp. 157-163 in Scott, P.W. and Walton, G. (Eds) Proceedings of the 15th Extractive Industry Geology Conference, EIG Conferences Ltd, 186pp.
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INTRODUCTION

A software tool *"PondSizer"*, originally developed as one of the main outputs from a MIST-funded project (MA/2/1/003) has been used by GWP Consultants over a number of years to calculate the sizes of attenuation ponds and settlement lagoons. Written in FORTRAN, PondSizer assists in sizing such structures so that the rate and quality of discharged quarry water meet regulatory requirements. Although successful in achieving its purpose it is recognised that it was not ideally suited for general, non-specialist use and that a more modern user-friendly version was required if it was to become more widely used. A new version has therefore been developed which uses a Graphical User Interface (GUI) with on-screen support and help, as well as providing some additional functionality. It is hoped that this software tool will become widely used by those with an interest in the environmental impacts of quarries, including quarry operators and managers, consultants, regulatory bodies, and other environmental organisations; but, particularly by those with responsibility for designing management systems for quarry water.

Commercial software packages are available that are designed to perform many types of calculations for drainage applications and some of these are able to calculate the sizes of attenuation ponds. However their cost (hundreds of pounds) is a disincentive to using them, certainly for small enterprises that are only likely to want to size ponds very occasionally. PondSizer is freely available and it is hoped that this will encourage its broader use. If this tool becomes widely used there should be consequent beneficial outcomes for the aquatic environment as a result of improved pond and lagoon design.

DEVELOPMENT OF THE SOFTWARE

The main core of PondSizer performs all of the calculations to generate the appropriate rainfall figures for a given location and calculates the dimensions of the attenuation ponds, settlement lagoons and sumps as required. It is written in the FORTRAN 90 programming language developed using the Microsoft Visual Studio Development Environment. This code is linked to a Graphical User Interface (GUI) 'front end' program that makes it possible for the user to interact with the application via a Windows environment. The GUI code was written in Visual Basic for Applications (VBA) and developed within the MS Access database structure. This made it possible to create a sophisticated GUI without the need to invest in the software development that would normally be required and which would not have been possible within the budget of this project.

The components of the PondSizer code were tested thoroughly; both separately and with the FORTRAN and VBA components fully integrated as a working trial version before it was sent out for evaluation and testing to members of a testing panel.

THIRD-PARTY SOFTWARE

PondSizer requires data from the Flood Estimation Handbook (FEH) CD ROM (Institute of Hydrology, 1999; Centre for Ecology and Hydrology, 2006), to generate rainfall distributions that are used in the calculations for all of the functions. Users of PondSizer therefore require a licensed copy of the FEH CD-ROM to generate the rainfall growth curve parameters. PondSizer also requires rainfall parameter values from the Flood Studies Report (FSR; NERC 1975). However these FSR data can be calculated using algorithms given in the FSR, which does not require a licence. Notwithstanding this, other electronic digital data, specifically Winter Rainfall Acceptance Potential (WRAP) data and the boundaries of the UK Hydrometric Areas and Regions, derived from the maps within the FSR, do require payment of a licence fee.

It was recognised that few users will have access to the FSR, particularly since the Flood Estimation Handbook has largely superseded it. Alternative methods of determining the WRAP values and Hydrometric Region were therefore incorporated into PondSizer.

FUNCTIONALITY AND ALGORITHMS

Overview

PondSizer calculates the dimensions of attenuation ponds and settlement lagoons linked by a single pipe containing a throttle plate with a circular orifice, or sumps with pumped outflow, for prescribed design rainfall events which have the option for climate change enhancement. Additionally the user may choose to calculate just the runoff, or the "greenfield" runoff, as described in "The SUDS Manual" (Woods-Ballard, 2007) and frequently required by the Environment Agency, or both. The user is able to specify the return period in years (mean annual probability), storm durations and profiles, climate change enhancement factors, surface (soil) types and runoff model, range of throttle plate orifice diameters or pump rates (for sumps), and other variables that are described in the dynamic help feature.

User selection of the various options and choice of parameter values is via the GUI which allows the user to select the desired type of calculation (*e.g.* pond or sump sizing, run-off calculations, *etc.*) and facilitates the selection by relatively inexperienced users of appropriate data and parameter values needed for those calculations. This is achieved using drop-down menus, buttons and forms with prompts, and lists of suggested parameter values. The user is prevented from selecting incompatible values. Dynamic Help screens also provide guidance to the user.

Calculation of rainfall rates

Rainfall rates are calculated using data from both the FSR and FEH. Of the two the FEH is generally considered to provide the more accurate estimates and is preferred by the EA. Moreover the estimates are generally more reliable, incorporating an additional 25 years of data and a new method for developing rainfall growth curves *viz*. Focussed Rainfall Growth curve Extension (FORGEX). This method was designed to represent more accurately the spatial variability in rainfall extremes than the FSR, which had been criticised as being over general. However, estimates of short duration rainfall (less than one hour) are less reliable than those given by the FSR. This is because calibration of the FSR rainfall method used short duration (less than one hour and down to five minutes) rainfall data from 150 stations whereas the shortest duration storms used in the calibration of the FEH model was one hour, albeit from many more stations. Rainfall distributions are produced by PondSizer using both the FEH duration-depth-frequency relationships and a model from the FSR for estimating the five-year return period rainfall together with growth curves. For rainfall events of one hour and longer the FEH estimates are used, for shorter durations the FSR estimates normalised by the FEH one-hour rainfall are used. This ensures that there are not discontinuities in the rainfall distributions at one hour duration and also that the greater spatial variability inherent in the FEH rainfall figures are reflected in the short duration events.

PondSizer allows the rainfall rates for a range of specified return periods and durations to be calculated for sites in nearly all parts of the UK, limited only by the areas that are included in the FEH CDROM database. The rainfalls can be calculated for a point or over a catchment using an areal reduction factor, F_A, given by Keers and Westcott (1977) and calculated using

$$F_A = 1 - aD^b$$

where D is the duration of the storm in hours, and a and b are given by

$$a = 0.4 - 0.0208.\log(4.6 - \log(A))$$

$$b = 0.0394.A^{0.354}$$

where A is the catchment area in km² for $A \le 20\text{km}^2$. For areas between 20km² and 100 km² the value of a is given by:

$$a = 0.4 - 0.00382.(4.6 - \log(A))^2 .$$

Calculation of runoff

At present four models are available to determine the runoff from the catchment, but they are all based upon the calculating overland flow Q (m³/s) as the difference between the rainfall rate P (mm/s) and f (mm/s), the infiltration capacity of the ground surfaces, multiplied by the catchment area. Thus

$$Q = 10.(P - f)A .$$

Consequently the runoff models are defined by the different methods used to calculate the infiltration rates *viz* the Horton constant rate, the Horton variable rate, the Green-Ampt, and the Green-Ampt PDM (Probability Distributed Moisture model).

The Horton equation estimates the infiltration rate $f(t)$ at time t as

$$f(t) = f_e + (f_i - f_e)e^{-\alpha t}$$

where f_e is the long term, final infiltration rate, f_i is the initial infiltration rate, and α is a parameter determined largely by surface texture. The infiltration parameters, f_e and f_i are dependent upon the surface type and cover, and f_e is also dependent upon the rainfall intensity, slope and initial substrate water content. Values of the parameters for a few surfaces taken from Wilson (1990) are given in Table 1. This model gives an infiltration rate that decreases with time to a constant value. The model referred to as the Horton constant rate is time independent and uses that constant value of $f(t) = f_e$, corresponding to $t = \infty$.

The Green-Ampt equation takes the form

$$f(t) = K_s\left(1 + \frac{(\theta_s - \theta)\psi}{F}\right)$$

where K_s is the hydraulic conductivity at saturation, ψ is the capillary suction, θ_s is the porosity and θ the residual saturation, and F is the depth of water infiltrated. The advantage with this equation is that the parameter values can be determined from the soil characteristics such as the percentage clay and sand (Rawls and Brakensiek, 1989).

Although using the infiltration capacity provides a physically-based method of estimating runoff, choosing a single infiltration value to represent the variation in infiltration with time does not account for the variation in infiltration capacity across a quarry. This can be modelled using a Probability Distributed Moisture model (PDM) which is described in detail in Moore (1985). The PDM deals with the frequency of occurrence of hydrological variables of certain magnitude over a catchment, without regard for the location of a particular occurrence within the catchment. For the Green-Ampt PDM, the Green-Ampt equation is used to calculate the maximum infiltration capacity across the catchment used in the PDM model.

surface		f_i (mm h^{-1})	f_e (mm h^{-1})	α (min^{-1})
sandy loam	bare	280	6-220	1.6
sandy loam	grassed	900	20-290	0.8
sandy clay	bare	210	2-25	2
sandy clay	grassed	670	10-30	1.4

Table 1. *Parameter values for the Horton equation from Wilson (1990)*

Sizing of ponds, sumps and lagoons

At present the program calculates the sizes of rectangular structures for a specified depth and side batter for each combination of the required return period and storm durations. Additionally the attenuation ponds and sumps are sized for the specified range of throttle plate orifices or pumping rates. The sizes of the settlement lagoons to achieve the required level of water clearing are determined by the outflow rates from the attenuation ponds or sumps. The sizes of the ponds are calculated using a water balance equation which gives S_i the storage (m^3) at time step i as

$$S_i = S_{i-1} + (Q - D)\Delta t$$

where S_{i-1} is the storage (m^3) in the pond at the previous time step i -1, Q is the run-off rate (m^3/s) into the pond, the difference between the rainfall and infiltration rates, and D is the outflow rate (m^3/s) from the pond through a throttle plate orifice during the time interval Δt (s).

The outflow through a throttle plate orifice is dependent upon the size of the orifice and the head of water. When the orifice diameter is much less than the diameter of the outlet pipe the rate of outflow, D, from the feed pipe can be calculated using,

$$D = C_D(d,h)d^2\sqrt{2gh}$$

where $C_D(d, h)$ is a discharge coefficient that is a function of, d the hole diameter, and h the head of water in the attenuation pond above the centre of the orifice. For large diameters and heads a constant value of 0.61 can be used without large error. g is the acceleration due to gravity.

For calculating the sizes of sumps the program uses specified pump rates in place of the drainage D through an orifice plate.

The area required for settlement lagoons to provide clearance of water is calculated from the rate of production of cleaned water Q_c (m^3/s) which must equal the rate at which water leaves (and enters) the settlement lagoon. The minimum lagoon area, A, (m^2) is that required to clear the water of particles having a settling velocity of u_s (m/s) calculated as

$$A = Q_c / u_s ,$$

Greenfield runoff

This is the rate of peak surface flows from an undeveloped area; it is often required for assessing flood risk and environmental impacts of new developments and for designing Sustainable Drainage Systems. It is dependent upon catchment area, rainfall rate and soil characteristics. The calculation of the greenfield rate in PondSizer follows the methodology given by Marshall and Bayliss (1994) and as recommended by Woods-Ballard *et al*, (2007). This method uses a regression equation relating the mean annual peak flow $\bar{q}$, to catchment area, mean annual rainfall and the catchment mean Winter Rainfall Acceptance Potential (WRAP) as defined and mapped across the UK in the Flood Studies Report (FSR).

So, the mean peak flow (m^3/s) for a small rural catchment, is

$$\bar{q} = 0.00108.A_{km}^{0.89}P_A^{1.17}\left(\frac{\sum a\sigma}{\sum a}\right) \quad \text{m}^3\text{/s}$$

where A_{km} is the catchment area in km^2, P_A is the standard average annual rainfall (mm), and the last term in parenthesis is the area-weighted mean of the soil types in the catchment, where the soils are categorised as one of five types (σ), given in the Flood Studies Report, according to its WRAP.

A Help screen lists WRAP values according to soil characteristics that the user can identify for their specific site. This has the advantage of removing the uncertainties involved in using large-scale maps for assigning the parameter.

The greenfield run-off rate is usually required for the 100% (annual), 3.33% (30 year) and 1% (100 year) mean annual probability events. Having calculated $\overline{q}$, the flow for the annual event, the other two flows are calculated by multiplying it by a factor determined from the appropriate regional growth curve given in the Flood Studies Supplementary Report 14. Selection of the appropriate curve is on the basis of the Hydrometric Region that the catchment is within. This can be determined either from the map given in the FSR or from the map of the hydrometric areas that is displayed at http://www.dundee.ac.uk/geography/cbhe/map.htm (this URL is given in the Help screen). The program calculates the relevant Hydrometric Region on the basis of the Hydrometric Area the user inputs.

OPERATION AND OUTPUT

For installing PondSizer on a computer three essential files are required, *viz* the executable file generated by the FORTRAN compiler, the GUI Access database, and a Salford FORTRAN library file. Two versions of the Microsoft Access database files have been created making it possible for users with different versions of Access to be able to run the program. GWP has the software necessary to provide royalty-free stand alone database files for users without Access. In addition, for each of these Access versions there are two versions available to ensure compatibility with Versions 1 and 2 of the FEH CD-ROM. However, until the licensing issue has been resolved GWP is not able to supply the necessary data files for users without their own copy of the FEH CD-ROM. It is expected that there will be future versions of PondSizer produced to correct any remaining bugs, to disseminate upgrades to the functionality, or to provide modifications that may be desirable in the light of new environmental legislation.

User interaction is through the GUI. The number of variables requiring user input varies depending upon the function being performed *e.g.* calculation of just the greenfield rate or just the rainfall distributions requires fewer variables than for sizing an attenuation pond and settlement lagoon. Table 2 shows the variables and options required for pond and lagoon sizing. When certain options are specified the GUI activates other dependent options: e.g. selecting the Horton equation (as the method for calculating the infiltration rates under *Item 5. Run-off model*) causes the Horton surface types to be displayed ready for selection under *Item 6 Catchment areas*.

Output appears in six files in the same directory as the executable file *viz*:

pondsize_data.dat

This file contains the dimensions of an attenuation pond (or sump) and settlement lagoon for every combination of return period, storm duration and throttle plate diameter (or pump rate). On occasions when the combination of rainfall events and soil permeability do not result in any predicted runoff from the catchment there will be no output record produced.

The entries in the file (Table 3) fall under the following abbreviated column heads:

R.P.	storm return period (years)
TPOD	throttle plate orifice diameter (mm)
DUR	storm duration (minutes)
IFLW_RT	rate of inflow (runoff) to pond (m^3/h)
TOT.IFL	total storm inflow (m^3)
TOT.AREA	total surface area (m^2) of the attenuation pond and settlement lagoon
SL_A	surface area (m^2) of the settlement lagoon
AP_A	surface area (m^2) of the attenuation pond
AP_VL.	volume (m^3) of the attenuation pond
DPTH	depth of the attenuation pond (m)
MX_OFW	maximum rate of outflow (m^3 /h)
24H_OFW	total outflow in 24 hours (m^3)
TFILL	time for the pond to fill (h)
TTMT	time for the pond to empty (h)
TTHMT	time for the pond to half empty (h)
RNFF_CO.	runoff coefficient for the storm (runoff/rainfall)

When PondSizer is used to size sumps the alternative abbreviations are used for the columns corresponding to the attenuation pond equivalents:

P.RATE	pump rate (m^3/h) in place of TPOD
SMP AREA	surface area of the sump (m^2) in place of AP_A
SM.DPTH	depth of sump (m) in place of DEPTH
SM.VOL	sump volume (m^3) in place of AP_VL

pondsizes.dat

This file (see Table 4[1]) is a summary file that contains a subset of the data given in pondsize_data.dat that corresponds to the largest total area of water for each return period and throttle plate orifice diameter. Fewer variables are given for each storm but there is one, the mean outflow rate that is not in pondsize_data.dat. The abbreviations used in the headers are the same as for the pondsize_data.dat file. The file contains another set of data that are a subset of the subset. These data give the dimensions of ponds with the smallest total surface area of water for each return period, thereby specifying the throttle plate diameter that minimises the space required for the pond and settlement lagoon. Finally there is another subset that specifies which storms give a runoff volume less than half the pond volume for ponds that will half empty in less time than a specified time. These data are useful for identifying ponds that, *e.g.* after a 100-year return-period storm, have sufficient capacity within, say, 24 hours to contain the runoff from a 30-year return-period storm.

pondsize_log.dat

This file contains output from the model that is a record of the run. It informs when the model has automatically changed the depth to be consistent with new side lengths and the required storage volume. It also contains any error messages that may be generated.

rainfall.dat, sum_rainfall.dat and win_rainfall.dat

These files list the rainfall for the range of specified storms for annual, summer and winter periods. Table 5[1] shows the contents of the annual file, *rainfall*.dat.

[1] *For copyright reasons the data displayed do not correspond to a real location,*

item	available primary options	dependent options			parameter values	units
1. Calculation type	rainfall distribution only					
	full pond calculation					
	sump calculations					
	soakaway calculations					
	greenfield calculations					
	runoff values only					
2. Options	output diagnostics					
	hydrometric areas					
	WRAP soil classes					
	FEH version 1					
	FEH version 2					
3. Return periods	***specify return periods***				1, 30, 100	years
	calculate return periods					
4. Storm durations	*specify return periods*					
			first storm duration		30	min.
	calculate return periods		last storm duration		360	min.
			duration increment		30	min.
5. Runoff model	*Horton constant infiltration rate*					
	Horton model infiltration rate					
	Green-Ampt model A infiltration					
	Green-Ampt model B infiltration					
6. Catchment areas	**WRAP**	WRAP	*surface type (Horton)*	*soils (Green-Ampt)*		
	surface type (Horton)	very low	*bare sandy loam*	*sand*		
	soils (Green-Ampt)	low	***grassed sandy loam***	*loamy sand*	20000	m^2
		moderate	*bare sandy-clay*	*sandy loam*		
		high	*grassed sandy-clay*	*loam*		
		very high	*Impermeable (5%)*	*silt loam*		
				clay loam		
				sandyclay loam		
				siltyclay loam		
				sandy clay		
				silty clay		
				clay		
7. Catchment data	*FEH catchment area*					
	actual area					
	Greenfield runoff hydrometric area				43	
8. Rainfall totals	***typical catchment***					
	point (1km grid)					
	apply areal reduction factor					
9. Meteorological factors	**climate change factor**				1.3	
	seasonal correction factor		*summer*			
			winter			
			uniform			
	storm profile		*75% winter*			
			50% summer			
10. Pond options	pond length initial guess				10	m
	pond width initial guess				10	m
	half-emptying time				24	h
11. Pond/lagoon options	lagoon length/width ratio				5	m
	pond maximum depth				2	m
	pond side batter				3	m
12. Throttle-plate orifice	initial orifice diameter				25	mm
	final orifice diameter				45	mm
	diameter increment				5	mm

Table 2. *PondSizer variable setup with typical values for a full pond calculation. Mutually exclusive options for various items are italicised. Where a choice is required the selected option is emboldened.*

Conclusions

A FORTRAN prototype PondSizer program was successfully integrated with a Visual Basic for Applications front-end program to produce a user friendly application for sizing water management structures. The costs of development of the program were kept low by using the MS Access database structure.

PondSizer is now freely available for general use by those who own the FEH CD-ROM by downloading from the GWP website (www.gwp.uk.com/research.html). Liaison with CEH will continue so that an arrangement is reached at the earliest opportunity to allow GWP to supply licensed data to those without the CD-ROM so that they too can use PondSizer.

return period (year)	orifice diameter (mm)	storm duration (min.)	inflow rate (m^3/h)	total inflow (m^3)	total area (m^2)	lagoon area (m^2)	a. pond* area (m^2)	a. pond* volume (m^3)	a. pond* depth (m)	maximum outflow (m^3/h)	outflow in 24h (m^3)	time to fill (h)	time to empty (h)	time to half empty (h)	runoff coefficient	rainfall (mm)
1	30	60	150	150	471	282	189	144	2.2	10.1	144.6	1	23.1	7.3	0.215	9.5
1	30	90	138	207	517	294	223	185	2.4	10.6	169.3	1.4	26.2	8.9	0.233	12.1
1	30	120	132	265	558	306	252	221	2.6	11	188.9	1.8	28.2	10.3	0.25	14.4
1	30	150	126	315	587	312	275	253	2.7	11.2	198.9	2.1	30.6	11.5	0.259	16.5
1	30	180	120	360	614	318	296	283	2.8	11.4	207.2	2.5	32.8	12.6	0.265	18.5
1	30	210	94	331	639	324	315	310	2.9	11.7	176.3	3.5	42.3	13.6	0.2222	20.3
1	30	240	89	359	661	329	331	334	3	11.9	180	4	44.7	14.4	0.222	22.1
1	30	270	85	383	675	329	346	357	3	11.9	179.5	4.5	47.8	15.4	0.222	23.5
omitted lines																
1	30	360	75	454	715	329	386	420	3	11.9	178.2	6	56.7	18.1	0.22	27.9
1	35	60	150	150	572	384	188	142	2.2	13.8	143	1	16.8	5.3	0.21	9.5
omitted lines																
1	35	360	75	454	828	449	379	409	3	16.2	242.9	6	40.5	13	0.22	27.9
1	40	60	150	150	687	501	186	141	2.2	18	141.1	1	12.7	4	0.21	9.5
omitted lines																
1	40	360	75	454	956	584	371	397	3	21	317.6	6	30	9.6	0.22	27.9
omitted lines																
30	30	60	150	150	766	329	437	506	3	11.9	190.1	1	63.9	22.1	0.32	22.1
30	30	210	94	331	1015	329	685	966	3	11.9	210.3	3	110.3	42.3	0.35	43.3
omitted lines																
30	35	240	266	1065	1163	449	714	1023	3	16.2	247.7	4	99.2	32.9	0.31	46.5
etc																

* a. pond = attenuation pond

Table 3. *Detailed output variables calculated by PondSizer and written to file* pondsize_data.dat.

User specified information

		units	example values
site details	*location (National Grid Ref)*		123456,987654
	annual rainfall	(mm)	789
	areas of sub-catchments	(m^2)	20000 10000
	sub-catchment surface type		8 9
rainfall infiltration model			Green-Ampt model
rainfall storm profile			Winter 75%
climate change factor			1.3
design storms	*return periods*	(years)	1, 30, 100
	storm duration	(minutes)	30, 60, 90, 120 150, 180, 210, 240, 270, 300, 330, 360, 390
attenuation pond	*side batter*		3
	half-emptying time	(hours)	24
settlement lagoon	*ratio of sides*		5

Pond Sizer calculated values

return period (year)	orifice diameter (mm)	storm duration (min.)	total inflow (m^3)	total area (m^2)	lagoon area (m^2)	lagoon length (m)	lagoon width (m)	a. pond* area (m^2)	a. pond* length (m)	a. pond* width (m)	a. pond* depth (m)	a. pond* volume (m^3)	maximum outflow (m^3/h)	mean outflow (m^3/h)	outflow in 24h (m^3)
parameters for the largest total area of water for each return period and orifice diameter															
1	30	360	455	715	329	31.4	10.5	386	19.6	19.6	3	421	11.9	7.4	178.2
1	35	360	455	828	449	36.7	12.2	379	19.5	19.5	3	410	16.2	10.1	342.9
1	40	360	455	956	584	41.9	14	371	19.3	19.3	3	398	21	13.2	317.6
30	30	360	1307	1161	329	31.4	10.5	832	28.8	28.8	3	1262	11.9	7.5	179.9
30	35	360	1307	1273	449	36.7	12.2	824	28.7	28.7	3	1246	16.2	10.2	245.1
30	40	360	1307	1399	584	41.9	14	815	28.5	28.5	3	1227	21	13.4	320.6
100	30	360	1812	1399	329	31.4	10.5	1070	32.7	32.7	3	1767	11.9	8.3	198.8
100	35	360	1812	1511	449	36.7	12.2	1062	32.6	32.6	3	1751	16.2	11.3	270.7
100	40	360	1812	1638	584	41.9	14	1053	32.5	32.5	3	1732	21	14.7	353.7
parameters for the smallest total area of water for each return period															
1	30	360	455	715	329	31.4	10.5	386	19.6	19.6	3	421	11.9	7.4	178.2
30	30	360	1307	1161	329	31.4	10.5	832	28.8	28.8	3	1262	11.9	7.5	179.9
100	30	360	1812	1399	329	31.4	10.5	1070	32.7	32.7	3	1767	11.9	8.3	198.8

storms giving an inflow volume ≥ half-volume of ponds above that have a half-emptying time ≥ that specified (24h)

return period (year)	orifice diameter (mm)	storm duration (min.)	half volume (m^3)
1	30	360	210.5
1	35	360	205
1	40	360	199

* a. pond = attenuation pond

Table 4. *Summary information written by PondSizer to file* pondsizes.dat.

PondSizer provides a relatively intuitive tool for those familiar with Windows applications that will assist in the correct sizing of attenuation ponds, settlement lagoons and sumps as will as providing the facility for calculating the greenfield runoff rate that is often required in assessments of flood risk and environmental impact.

It is hoped that widespread use of PondSizer will contribute to reducing deleterious impacts on the water environment from quarry operations through the improved design of ponds and lagoons, and increased compliance with Environment Agency discharge consents.

rainfall depth (mm) at Nat. Grid Ref.			123456, 98765
climate change factor			1.3
Standard period (1961 – 1990) Average Annual Rainfall (mm)			789

duration	return period (years)		
(min.)	1	30	100
60	9.5	22.1	30
90	12.1	27.6	36.9
120	14.4	32.1	42.8
150	16.5	36.1	48
180	18.5	39.9	52.6
210	20.3	43.3	56.9
240	22	46.5	61
270	23.5	49.5	64.7
300	25.1	52.4	68.3
330	26.5	55.1	71.6
360	27.9	57.7	74.9

Table 5. *Rainfall data as calculated and written to file* rainfall.dat *by PondSizer using the Flood Estimation Handbook parameters.*

ACKNOWLEDGEMENTS

The development of PondSizer was funded by the DEFRA Aggregates Levy Sustainability Fund and managed by the Minerals Industry Research Organisation. The work was supported by Aggregates Industries as an industrial partner.

REFERENCES

Centre for Ecology and Hydrology, 2006 Flood Estimation Handbook CD-ROM version 2.0. Centre for Ecology and Hydrology Wallingford. www.ceh.ac.uk/feh

Institute of Hydrology, 1999 Flood Estimation Handbook CD-ROM version 1.0. Institute of Hydrology Wallingford.

Keers, J.F. and Westcott, P. 1977 A computer-based model for design rainfall in the United Kingdom. Met. Office Scientific Paper No. 36. HMSO, London

Marshall, D.C.W and Bayliss, A.C. 1994. Flood Estimation for small catchments, Report No. 124, Institute of Hydrology, Wallingford.

Moore, R.J. 1985 The probability-distributed principle and runoff production at point and basin scales Hydrological Sciences Journal 30: 273-297.

NERC, 1975 Flood Studies Report (5 volumes), Natural Environment Research Council, London

Rawls, W.J., Brakensiek, D.L and Miller, N.1983 Green-Ampt infiltration parameters from soil data. Journal of Hydraulic Engineering, 109, 62-70.

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R. and Shaffer, P. 2007. The SUDS Manual , C697, CIRIA, London