Estimating the rainfall/run-off component of water abstracted from quarry sumps.

1.0 Background

The Water Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006, came into force in February 2007 and require the licensing of water abstraction where this exceeds 20m^3/day.

In many quarries water is pumped or discharges by gravity from one or more sump areas, usually located with a lower elevation portion of the quarry. Abstraction of groundwater from boreholes drilled in the quarry floor or adjacent to the quarry working area can also take place. Water may also be abstracted from local watercourses by diversion or pumping.

The water pumped out of a quarry sump normally consists of two* main components:

a) ‘surface water’ from local catchment surface rainfall run-off.

b) ‘groundwater’ where the sump extends below the (pre-quarrying) natural water table and where there is some degree of hydraulic contact between the sump and the surrounding strata (this will almost always be the case, unless some form of engineered liner has been installed.)

For the purposes of abstraction licensing charging, an estimate of the volume of water abstracted from a sump is required, recognising that the entire volume pumped will also comprise quarry drainage, local surface catchment run-off and incident rainfall. Surface water run-off is not a licensable component of the total volume abstracted under the Regulations. Whilst understanding the different components of the water balance in detail for quarries may be justified in certain cases with respect to prediction of impact on the local water environment, undertaking this level of assessment for the purposes of abstraction licensing charging could be considered as excessive.

The purpose of this report is to consider an option for producing a simple method that allows an acceptable estimate of the surface water run-off component that is abstracted from a quarry sump.
This method proposes to estimate the surface water run-off and subtract this from the total gauged or recorded volume of water discharged from the quarry sump or exported in product.

* There may in some cases be some public supply mains water draining to sump.

2.0 Estimation of long-term average surface water run-off.

The Meteorological Office (UK) publishes datasets of both long-term standardised annual average rainfall (SAAR) and annual average potential evapo-transpiration (AAPE). The most recent datasets, considered to be representative of current Northern Ireland climate conditions are for the period 1971 – 2000. The data is published at a 1km grid resolution, so each 1km square in Northern Ireland has representative SAAR and AAPE values.

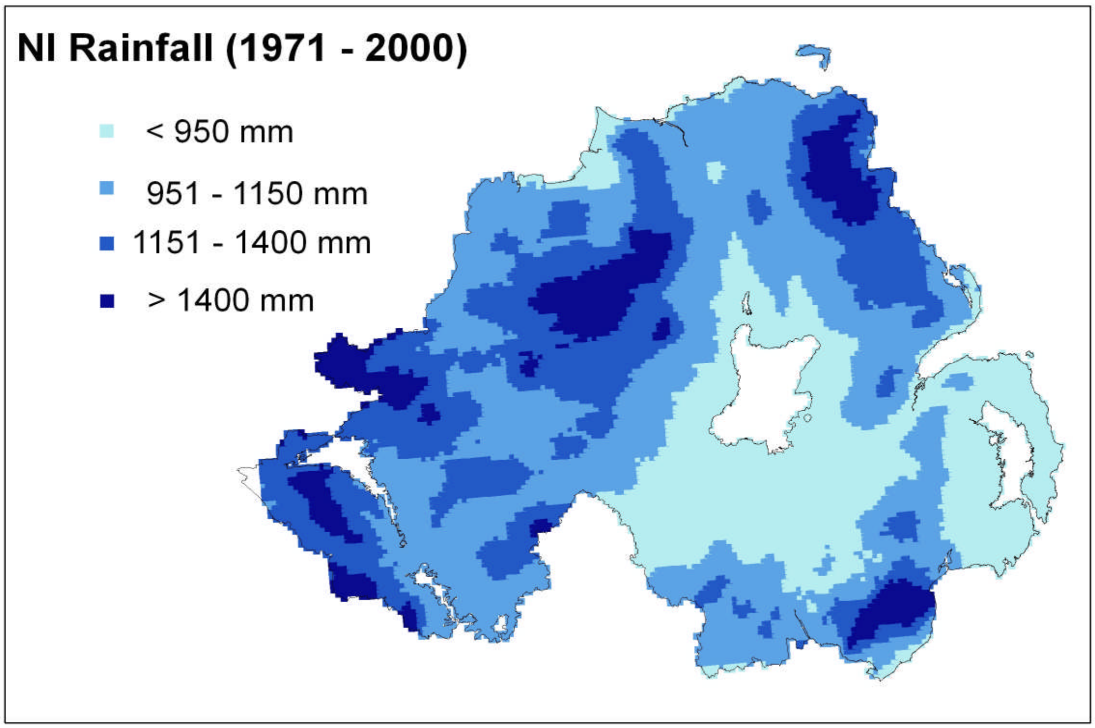

Figure 1. Standardised Annual Average Rainfall in mm (1971-2000)

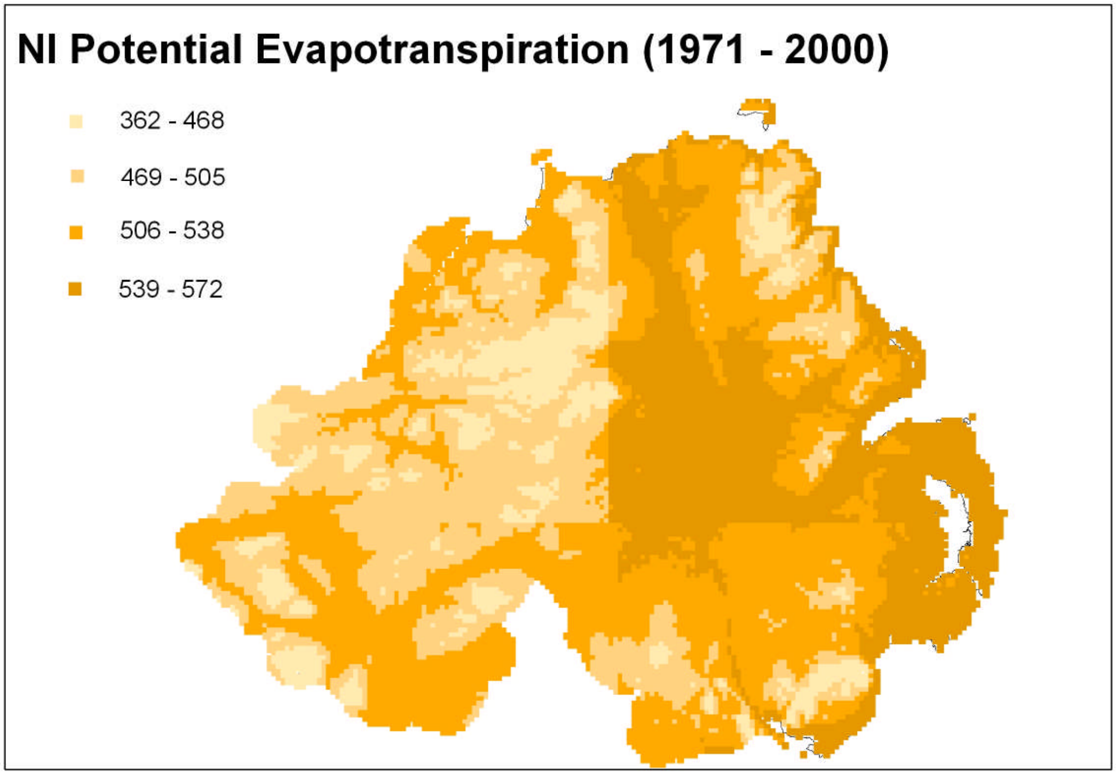

Figure 2. Annual Average Potential Evapo-transpiration in mm (1971-2000)

Figures 1. and 2. show the distribution and variation of these climatic parameters across Northern Ireland. It is clear to see that both distributions are closely reflective of differences in altitude. Analysis and computation of these datasets allows for the generation of a run-off depth distribution map. Simplistically, run-off depth can be calculated as the rainfall less the potential evapo-transpiration:

Annual Average Run-Off Depth	**=**	**Standardised Annual Average Rainfall**	**-**	**Annual Average Potential Evapo-transpiration**
(mm/year)		**(mm/year)**		**(mm/year)**

Run-off is potentially generated within any given surface water catchment area that drains in to the quarry void and ultimately the sump or lagoons. Where stream diversions are in place to divert streams or surface flow around the quarry void, little or no surface water may drain into void and only incident rainfall accounts for the sump volume not abstracted from groundwater or other active abstraction processes. The distribution and variation of the calculated run-off depths are shown in Figure 3.

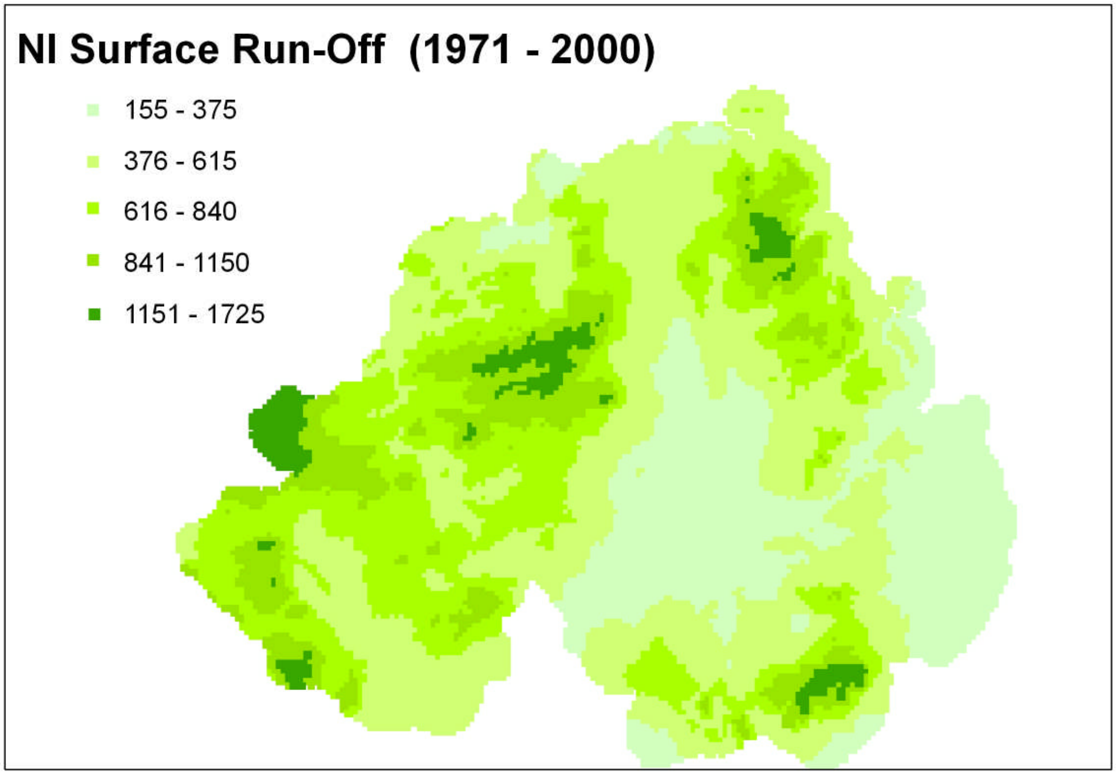

Figure 3. Annual Average Run-off Depth in mm (1971 – 2000)

The potential run-off for any given surface water catchment area can easily be calculated by multiplying the area in km^2 by the run-off depth in mm, to yield the volume in m^3/year. The annual daily average volume can then simply by calculated by dividing this figure by number of days in year.

3.0 Groundwater Recharge

Not all the run-off generated within the catchment will be available to form surface water flow. A proportion will infiltrate through the soil surface and percolate through sub-soil layers to recharge groundwater held in superficial deposits or bedrock. This proportion is dependant on many factors such as the soil and sub-soil hydrological characteristics and the nature and depth of the groundwater aquifer. Even for the most impervious bedrock types a groundwater recharge of 100 mm/year is typical. For superficial aquifers such as glacial sand and gravel deposits, the annual recharge value is likely to be a minimum of 350mm/year[†]. To account for this range in potential groundwater infiltration rates for different catchments, the 2 stated groundwater recharge values will be applied to reduce the calculated run-off for bedrock and sand and gravel quarries respectively.

† Robins, N.S., 1996, The Hydrogeology of Northern Ireland, HMSO for the British Geological Survey

Therefore, the run-off can now be corrected to account for the losses from groundwater recharge within the catchment area of the quarry, as below:

Annual Average Run-Off Depth	**-**	**Groundwater Recharge Annual Average**	**=**	**Annual Average Run-Off Depth (Modified)**
(mm/year)		**(mm/year)**		**(mm/year)**

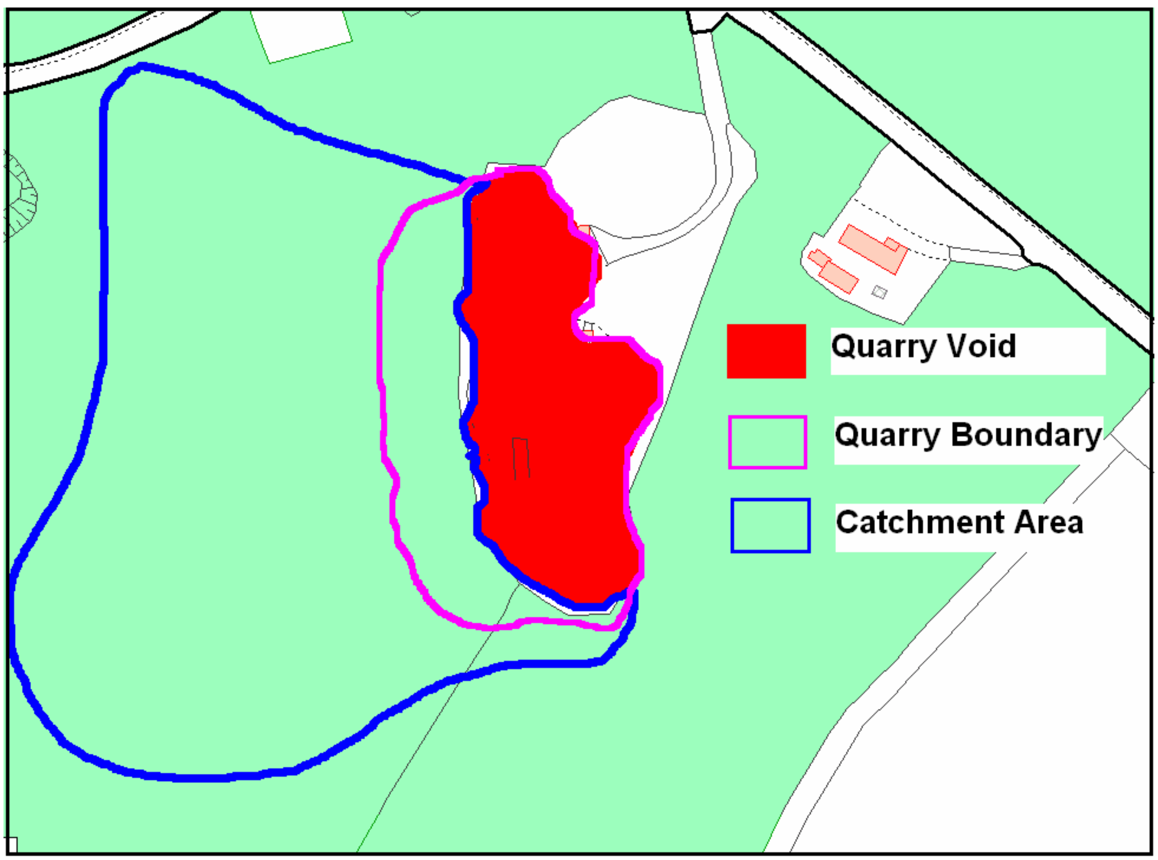

Figure 4. Example of a typical quarry hydrological catchment

Figure 4 represents a typical quarry layout with quarry void, quarry boundary and surface water catchment identified. In this case it is assumed that surface water flow is free to run across ground or through watercourses into the quarry void.

Example 1:

Catchment area (km^2)	**=**	**0.025**
SAAR (mm)	**=**	**1000**
AAPE (mm)	**=**	**250**
Quarry type	**=**	**Bedrock (Granite)**
Groundwater Recharge (mm)	**=**	**100 (Bedrock)**

1) Run-Off Depth = SAAR(mm) – AAPE(mm) – GWR (mm) = AARD(mm)

= 1000 - 250 - 100 = 650 mm

2) Surface Flow = AARD(mm) x Area(km^2) x Factor* = Flow (m^3/day)

= 650 x 0.025 x 2.73888 = 44.5

**Factor converts (mm/year x km^2) to m^3/day*

In this example, the total catchment area of 0.025 km^2 or 25,000m^2 generates a surface water flow of 44.5 m^3 per day, as an annual average. However, due to seasonal variations in rainfall and temperature during the year, run-off potential will be reduced significantly during the drier summer months. This is primarily due to reduced rainfall in summer but developed soil moisture deficits and other factors may also have an effect. To allow for this variation, a template may be applied to the proportion of the annual run-off values to individual months. This template is derived from the long term monthly average rainfall for the period 1971 – 2000 for the whole of Northern Ireland, as shown in Table 1.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Annual Rainfall (mm)	119.1	86.5	93.4	70.6	68.1	72.1	73.2	90.8	94.4	114.5	110.5	118.5
% of Annual Total	10.7	7.8	8.4	6.4	6.1	6.5	6.6	8.2	8.5	10.3	9.9	10.7
Monthly /Annual Factor	1.28	0.94	1.01	0.77	0.73	0.78	0.79	0.98	1.02	1.24	1.19	1.28

Table 1. Monthly Average Rainfall % of Annual Total and Mean Monthly/Mean Annual Factors for Northern Ireland (1971 – 2000)

Table 1 shows that long term average daily rainfall varies from 0.73 times the annual mean in May to 1.28 times the annual mean during December and January. It is proposed to apply this monthly rainfall variation templates to to the long term annual average run-off value to allow for adjustment to monthly abstraction values that may be stated on the application. Although potential evapo-transpiration will also vary seasonally, it is perhaps overly complex to re-adjust for this as rainfall is the primary driver for direct run-off variation.

Example 2:

Mean annual daily run-off: **44.5 m^3/day**

During month of May run-off adjusted to: **44.5 X 0.73 = 32.5 m^3/day**

During month of December run-off adjusted to: 44.5 X 1.28 = 57.0 m^3/day

4.0 Incident rainfall

This is the component of the rainfall that does not 'run-off' to the quarry void but falls directly into the quarry void, including the sump. It may be argued that such rainfall is not subject to as much potential evapo-transpiration as it does not fall on ground covered with vegetation allowing for plant uptake and subsequent transpiration or on soil, allowing for infiltration and percolation to groundwater. However, incident rainfall draining through the quarry void is subject to losses through infiltration to groundwater. Water held in quarry sump can also be considered to be open water and subject to high potential evaporation. Given the scale of quarry voids, boundary areas and catchment areas, it is thought appropriate to apply a single SAAR value and PE value to each quarry site as the data is available at 1km grid scale only. Resolution of available data to the scale of the typical quarry in Northern Ireland would require some considerable effort and given the hydrological risk posed by the scale of quarrying activities, this is deemed inappropriate.

5.0 Conclusion

The monthly or annual surface run-off component established for a quarry operation can then by adopted to calculate the net licensable abstraction from any site. Records of the water use from the quarrying operation are required to ascertain the total used consumptively, using the ready-reckoner, and the total volume discharged from the sump to a local waterway or elsewhere.

6. Glossary

Aquifer
An underground permeable water-bearing rock or deposit formation capable of yielding exploitable quantities of water.

Catchment
An area having a common outlet or discharge point for surface water flow (also known as a watershed).

Evapo-transpiration
The process by which water is transferred from the soil to the atmosphere by evaporation and plant transpiration.

Groundwater
Sub-surface (underground) water occupying the saturated zone of an aquifer.

Groundwater Recharge
The process by which water is added to the saturated zone of an aquifer from outside it, either directly or indirectly.

Run-off
The part of precipitation (rainfall) that appears as streamflow.